How can faba-bean cropping contribute to a more sustainable future European agriculture?

Analysis of transition opportunities and barriers in Denmark

Lybæk, Rikke; Hauggaard-Nielsen, Henrik; Kjær, Tyge

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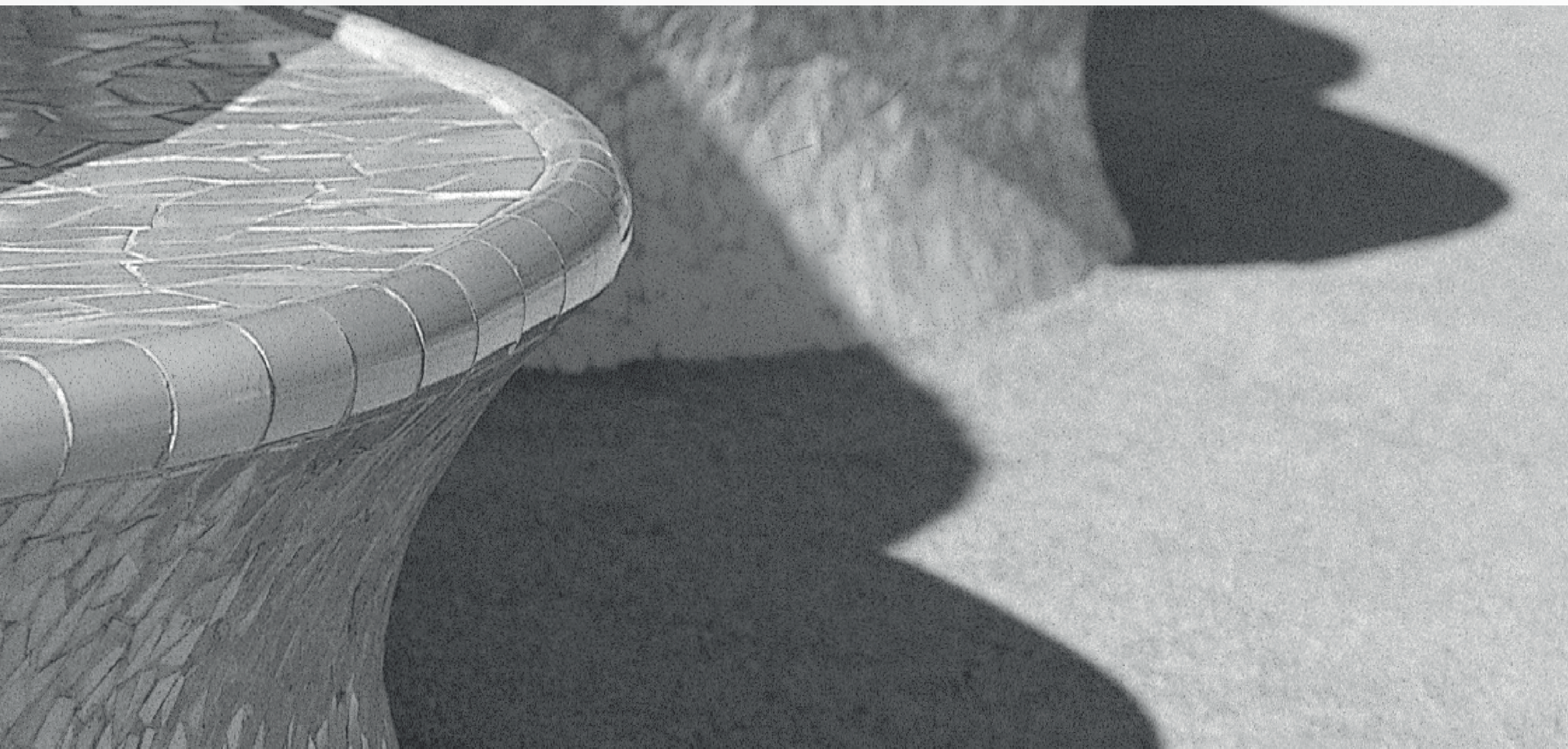

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Editors' Preface

The European Roundtable for Sustainable Consumption and Production - ERSCP is one of Europe's most remarkable conferences in its field and has taken place periodically since 1994. ERSCPs favour discussions about the key issues in sustainable consumption and production, the exchange of thoughts, knowledge, experiences and SCP proposals and the creation of a European (also worldwide) community of research and practice in sustainable consumption and production. The main goal of the ERSCPs is to encourage discussion amongst stakeholders involved in sustainable consumption and production: businesses, public institutions, universities, institutes and research centres, NGOs, SMEs, professional associations, decision-makers, etc.

The 19th European Roundtable for Sustainable Consumption and Production Conference was held in Barcelona, from 15 to 18 October2019. It was organised by the Institute for Sustainability Science and Technology of the Universitat Politècnica de Catalunya - BarcelonaTech in cooperation with the ERSCP Society.

Participants from almost 40 different countries contributed their work to the conference. Different parallel events took place during the event, such as the 'Circular Design Conference'; the 'European Network for Research, Good practice and Innovation fur Sustainable Energy - ENERGISE'; a discussion session on Sustainable Consumption and Care held by the 'Sustainable Consumption Research and Action Initiative – SCORAI Europe' and a PhD day. The 19th ERSCP encouraged event sustainability among its participants and took action to organise a sustainable conference through diverse initiatives, such as proposing a voluntary CO^2 compensation programme, promoting a zero-waste conference event, and fostering specific sustainable consumption practices.

19th ERSCP conference proceedings are organised in a 'Book of abstract' and a 'Book of full papers'; the latter, consisting of two volumes. Respectively, 196 abstracts and 110 full papers are included. Each book and each volume has a separate ISBN number. The proceedings will be available for conference delegates and ERSCP members in digital format.

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- Creative approaches in sustainable consumption & lifestyle
- Cross cutting design
- Cross Cutting Policy
- Cross cutting transdisciplinarity
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- Sustainable buildings and architecture
- Sustainable cities and communities
- Sustainable ethical investments
- Sustainable management and operations
- Visioning for transitions to scp and a circular economy
- Zero waste economy

KEYNOTE SPEAKERS

Prof. Arne Remmen

Aalborg University, Denmark

Abstract: The roots of circular economy – from cleaner production over eco-design to sustainable business models

Prof. Giorgo Kallis

Univesitat Autónoma de Barcelona, Spain

Abstract: Limits. Why Malthus Was Wrong and Why Environmentalists Should Care

Prof. Conny Baker

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Abstract: Making sense of the circular economy

Prof. Kristen Gram-Hanssen

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Abstract: Consumer roles and everyday practices in a reconfigured renewable and circular energy system

Dr. Didac Ferrer

Universitat Politècnica de Catalunya, Spain

Abstract: The path towards a sustainable community. A collaborative approach inspired by living systems

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Circular Design

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Implementation of Recycled Thermoplastics into Furniture Design

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Abstract

The main problem with wasting polymers is the negative environmental impact they create when compared to the reduced amount of time they are used. Currently, polymers are the best materials for packaging and transportation purposes. They are light, inexpensive, easily malleable, strong, resistant to environmental changes and very durable. All these good features allowed plastic to replace other traditional options with less environmental impact, such as wood, paper, cardboard or glass. Thermoplastics demand will continue to grow through the years; therefore, recycling assumes itself as a possibility that has to be increasingly implemented. Furniture is a promising product to combine with recycled thermoplastics. Its long life creates a perfect contrast to the common short-term use of many thermoplastic products. To promote and disseminate the importance of implementing recycled plastic products, it is necessary to design objects that meet the current needs of consumers. This objective is difficult to achieve since in today's society, the availability of recycled material is limited, its processing has some constraints, and most of the products obtained are not appealing to consumers. In the Master Program of Product and Industrial Design of University of Porto, in the curricular units of project design, and product and industrial design, students are encouraged to develop products taking into account issues related to sustainability and eco-design. The other curricular units of the master degree contribute to the projects in progress, providing and criticizing the choices made by students considering the lectures given. After completing the project, students have the possibility to develop in their dissertations the products, aiming at their industrialization, with or without industrial partners. This communication presents the project developed by one of the students, with the support of the workshops of the two Faculties that teach the master degree. After several brainstorming sessions, it was decided that a sitting stool would be the furniture to be designed and developed. The stool is one of the simplest and oldest forms of portable human support. The object involves all the physical and mechanical challenges, since it must support an average human body weight. In addition, given the average dimensions, it is easy to make a real scale prototype. All the development stages of the sitting tripod stool that was conceived using thermoplastic waste are presented. The manufacturing methods were implemented at an experimental level. They may be considered craftsmanship actions and had no focus towards mass-production. The stool has a recycled HDPE seat and threaded solid beech wooden legs. The flat surface promotes its use as a side or small table besides seating. However, when several artefacts are seen together, they invite the user in joining them to create diverse combinations or patterns. The stool seat achieved an attractive and unique colour pattern that evokes curiosity about the material origin, thus, it promotes and raises awareness of the benefits of implementing recycled thermoplastics in furniture design.

Keywords: Design, HDPE, Furniture, Recycling, Thermoplastics

1. Introduction

Plastic materials are subdivided into two main categories, thermosets and thermoplastics. Thermoplastics are easy to recycle and reshape (Shen and Worrell, 2014). The environmental advantage of using thermoplastics is then their ability to be re-used. Currently, plastics are the best materials for packaging and transportation purposes. They are usually light, cheap, easily malleable, strong, resistant to environmental changes, and very durable. All these positive qualities allowed them to replace traditional materials such as wood, paper, cardboard and glass which have less environmental impact. Almost 40% of the European plastic demand is dedicated to packaging, and for this specific application, it is expected a global growth up to 12% yearly (PlasticsEurope, 2016; Shah et al., 2008).

The main problem with plastic packaging is the negative environmental impact it creates compared to the reduced amount of time it is used. The packaging only serves as a transportation vehicle or protection device, once the object inside is accessed, the container is immediately discarded. Most of the plastics do not even fulfil a long- term use, thus, becoming a big waste problem (Luijsterburg and Goossens, 2014). Currently, this is the main global environmental issue; waste amounts are increasing, while materials alternatives and re-utilization rates are not growing proportionally.

Given the furniture nature, its dimensions, and materials employed, they are normally seen as objects that will last for years, if not decades (Leslie and Reimer, 2003). Furniture is the ideal product to combine with recycled plastics. The extended life creates a perfect contrast to the short-term life of common thermoplastic products.

Everybody has a different point of view of what can be considered "sustainable". Although there is no evident meaning to the word, product designers have the obligation to find and apply the most appropriate solutions and tools recently available in this important topic (Karlsson and Luttropp, 2006).

There is a clear trend in the production of "green" goods, but there is still a controversy over what can be considered a sustainable product (Dangelico and Pujari, 2010). The objective is clear when applying eco-design to furniture, the main focus is to use less materials and energy in the manufacturing process, and to ensure that the applied material is the most efficient in terms of environmental impact, cost and social awareness (Yüksel and Kiliç, 2015).

Design can be considered the most important part of a product development process; most of the great decisions are taken during this stage. It has been estimated that 85% of the issues with manufactured goods were a result of a mediocre design practice. It is estimated that 5% of a product total cost is dedicated to the design phase, however, around 75% of the production costs are estimated or, committed in this early stage (Ullman, 2010). This means that design can be the easiest and cheapest way where big sustainable positive impacts can be applied (Ramani et al., 2010).

The implementation of eco-design in product design can be achieved in various ways. Certain rules or checkpoints can be applied to the object specifications. A clear example of this methodology is Luttropp's 10 Golden rules (Luttropp and Lagerstedt, 2006), where he summarizes several papers on eco-design practices and comes up with ten simple rules to follow, to develop an efficient and sustainable product.

A survey of specific needs for sustainable furniture was carried out by evaluating various articles and

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standards (International Organization of Standardization, 2002; Ljungberg, 2007; Luttropp and Lagerstedt, 2006; Rocha et al., 2011; SIEMENS, 2000; Wimmer and Züst, 2003). Several characteristics were implemented to obtain the best representation of sustainable furniture. To simplify this stage, some activities were not considered, for example: packaging, sales, marketing, customer information and transport or assembly instructions.

Eco-design aspects considered in this publication are:

- Reduce the number of components;
- Minimize the different types of material;
- Minimize the usage of installation or assembly tools;
- Employ recycled materials;
- Use better-quality materials that will extend the product life and reduce maintenance;
- Design for reuse, recovery and recycling;
- Avoid toxic substances, materials, finishes, additives or coatings;
- Consider human health during manufacturing (proper safety gear and avoid hazardous materials);
- Use local materials (shorter distances are better);
- Low energy consumption during manufacture;
- Avoid using fasteners, connectors or fixings;
- Avoid using composites, mixes, blends, coatings, additives or alloys.

Recycling can be one of the best ways to reduce the environmental impact of a manufactured good. In the case of thermoplastics, using recycled instead of virgin material is currently the best way to contribute to the reduction of the negative impact of the polymer waste in the ecosystem (Hopewell et al., 2009).

More products or solutions to use recycled thermoplastics have to be implemented. It is easy to re-use and recycle, and more important, it is an abundant material, and production will continue to grow. All the people enrolled with polymers manufacturing and processing have the moral obligation to take advantage of this waste material and make people understand that these polymers can be re-used without losing the main mechanical and physical properties, therefore, the collection and separation of these plastics can grow. In 2016, 19 countries had plastic packaging recycling rates higher than 35%. Two countries achieved a recycling rate of 50% or more (Germany and Czech Republic) (PlasticsEurope, 2018).

Recycled thermoplastic is not a common raw material used in the industry sector, but technology, social trends, market direction, and an increase in production are creating new investment opportunities. Not only is it becoming a new business sector, but also the use of recycled thermoplastics is maximizing the environmental benefits compared to the use of traditional virgin plastics (WRAP, 2010). The problem with recycling is that every time the plastics are reprocessed, mechanical properties will be lowered with each repetition (Santana and Manrich, 2003).

Plastic waste can end up with very different outcomes; it can be recycled, incinerated, disposed, buried or piled up in landfills. A report made by the association Worldwide Responsible Accredited Production (WRAP), analysed different disposals (recycling, incineration with energy recovery, landfill and pyrolysis) of plastics and evaluated the most beneficial ones to the environment, and concluded that: “The results show that mechanical recycling is the best alternative regarding the climate change potential, depletion of natural resources and energy demand." (WRAP, 2010).

Life Cycle Analysis studies (Arena et al., 2003; Perugini et al, 2005) of the Italian plastic recycling system, concluded that mechanical recycling was the best waste management option from an environmental perspective. This shows that recycling is the correct way of handling plastic waste, and the next step would be to create products or valuable goods that use recycled thermoplastics as their main raw material.

Some of the requirements that must be applied in order to improve an artefact that utilizes recycled thermoplastics (Hunt et al., 2015; Ljungberg, 2007; Maris et al., 2014; Shen and Worrell, 2014; Thierry et al., 1995) are:

- Recycled materials should maintain their main mechanical and chemical properties;
- Parts and components should include the correct thermoplastic recycling code;
- Must be able to be sorted out by recycling companies;
- Easy to transform and sort out having in mind a good cost-to-performance ratio;
- Avoid the use of composite materials;
- Use of fasteners instead of glue or screws;
- Components must be easy to disassemble and categorize;
- Additives, fillers and coatings must be avoided if they affect the recycling process.

Pieces of furniture are desired items that complement aesthetically and emotionally the house, they complete our own interior common space (Postell, 2012). Using recycled materials in daily objects is the best way to represent plastic problem and create consciousness in the society.

A piece of furniture is commonly used for several years, unlike the short-term life of plastic packaging objects. One of the biggest advantages of using recycled thermoplastics in furniture is then their usage in better and more durable applications. A clear product example of this would be the "111 Navy Chair", a chair made from one hundred and one recycled Coca Cola bottles; "We've turned something many people throw away into something you want and can keep for a long, long time" (Hickman, 2010).

The choosing of the materials that will be used for producing components in furniture is a key part in the design process. The material that causes less damage to the environment should be the priority (Yüksel and Kiliç, 2015). The first area that should be looked upon in design, is the disassembly of the furniture itself. Recycling of a product cannot be promoted if the object is not easily disarmed in order to divide and classify the materials independently. Furniture should be designed for remanufacturing after consumer use, thus, the user can assist in the process of material reuse (Bogue, 2007; Hauschild et al, 2004).

One of the biggest challenges that affect modern furniture design is the current decrease of living space. Residencies are getting smaller, especially in crowded cities. This new reality creates a new need in the furniture industry. A report made by Urban Land Institute (Riggs, T., 2014) concluded that in the USA there is a noticeable decrease in the living space units; studio and one-bedroom apartments construction is on the rise and micro apartments are becoming a trend in the housing market.

2. Methods

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After several brainstorming sessions, it was decided that a seating stool would be the furniture to be designed and developed. The bench is one of the simplest and oldest portable forms of human support (Postell, 2012). The artefact involves all physical and mechanical challenges, as it must withstand an average body weight. In addition,given the average size, it is easy to create a real-scale prototype.

Due to issues of aesthetics, social trends and visual aspects, thermoplastics will not be the only material applied in the components of the product. After an evaluation of current furniture, it was decided that wood would be combined as a complementary piece in the stool design. This was mainly due to its traditional background throughout furniture applications and its appealing look when combined with plastic.

With size becoming the biggest problem in modern housing, transformable furniture may be one way to solve the current space problems (Wang, 2013). The amount of furniture that will be used will be limited by the available space, thus, these products will need to serve more than one purpose or activity; “Furniture has come to more closely resemble clothing in terms of the need for spatial mobility and flexibility” (Leslie & Reimer, 2003).

Designing multi-functional furniture can easily become a very complex and structured product, therefore, in this research, the goal was to try to keep the object as simple as possible. The additional functions must be well defined and cannot have too many alternative purposes. Secondary features cannot interfere with the main objective of the product; if these variables are ignored, the furniture may become inefficient (Özçelik and Kaprol, 2016).

Easiness in assembling and disassembling can be considered a quality of multifunctional furniture. Ready-to-assemble (RTA) furniture is considered a type of furniture that uses numerous kinds of fasteners, instead of the traditional glue joining technique. This type of furniture is widely used in the market and can be considered as a new (compared to gluing techniques) method of joinery (Simek et al., 2010; Uysal, 2014).

One of the key aspects of this piece of furniture is to transmit the positive outcomes of creating products that implement recycled thermoplastics in their components. The stool proves that recycled plastic can have unique and attractive forms, patterns and shapes. The seat should transmit the impression of a common or known material. However, a closer look reveals imperfections that should become obvious. Therefore, a controversy about the material origin will arise, causing curiosity and excitement.

After this initial phase, the following requirements were established for the product:

- Product: Furniture – stool;
- Background: Intended for international use;
- Added features: Eco-efficient, multi-functional, RTA;
- Other functions besides stool: Side table and coffee table;
- Aesthetic factors: Simple;
- Materials: Recycled plastic (HDPE) and beech wood (since wood will be applied in the stool legs it is very important to consider the wood grain direction - compression forces should be perpendicular to the cellular wood shafts);
- Prototype manufacturing method: Restricted to the faculties’ laboratories capacities.

The advantage of recycling plastics in furniture design is the several outcomes that can be obtained in terms of textures, colours, or finishing patterns.

All the manufacturing methods were implemented at an experimental level with different type of thermoplastics and moulds, developed during one academic year of a master thesis (Silva, 2018). They may be considered craftsmanship actions and had no focus towards mass-production. Several processes and techniques were tried

and analysed; however, not all of them met the needs. Figures 1 and 2 show the first sketches and attempts to make the stool (piñata stool, since the seat colours resembled a Mexican traditional festivity object).

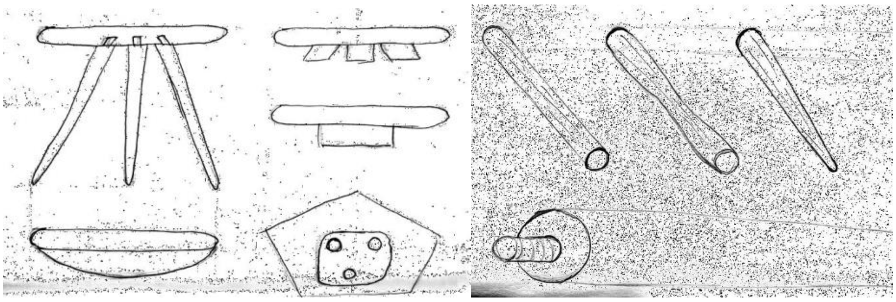

***Figure 1**. First ideas and sketches.*

***Figure 2**. First stool made from recycled HDPE and wood waste.*

Although no advanced design was applied to the creation of the piñata stool, the first contact emerged from how to use recycled plastic as an effective material for a stool seat. This is considered the first unintentional prototype of this research paper. After this phase, the design of the piece evolved, as well as the manufacturing process that became more elaborate. A tripod stool prototype was made to test out the threaded leg resistance and stability at different inclination angles (Figure 3).

***Figure 3**. Detail of the second prototype and tests with different legs design attachment system to the stool base.*

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The best method that worked properly when using recycled thermoplastics was the implementation of wooden moulds with final shaping obtained through a CNC machine (Figure 4).

Figure 4*. Manufacturing stages (from left to right); (a) weighing the plastic, (b) melted plastic inside metallic containers, (c) wooden rectangular mould, (d) application of a load during cooling, (e) retrieval of piece after cooling down, (f) rectifying into uniform rectangular shape, (g) after CNC process, making pre-holes, (h) threading holes for legs.*

3. Results and Discussion

The final prototype is a modular sitting stool (4,3 kg, 0.8 kg beech wooden legs, and 3.5 kg recycled HDPE seat) with an uncommon lunar shape (Figure 5). The seat is entirely made from industrial recycled HDPE, and no additives or coatings were added or applied. After several experiments with different thermoplastics (PET, LDPE, PP and PS), HDPE had the best aesthetic, mechanical and manufacturing characteristics. The unique flow-like patterns and colour combinations give it a unique and curious look.

This final designed product is called “Gibada”, which is the Spanish word for gibbous. The origin of this word is due to the seat shape that is very similar to a gibbous lunar phase.

Figure 5. *Final stool prototype, HDPE lunar-shape seat with threaded beech wood conic legs.*

The stool conic tripod legs are made from solid European beech wood. They have a protective layer of natural beeswax. Beech wood was chosen due to its dense and aesthetical features and the grain compaction that made it the ideal candidate for the leg threaded end.

When a stool is observed, it transmits the sense of a single and unique furniture piece. The flat surface promotes the use as a side or small table besides sitting. However, when several artefacts are seen together, they invite the user to join them and create diverse combinations or patterns (Figure 6). This creates a hidden modular feature that does not appear at plain sight, it arises through the need of more units.

Figure 6. *Multi-functional possibilities for the stool.*

The reshaping of thermoplastics offers several different outcomes in textures, colours and finishes. The results applied in the product design were beyond expected. Not only was created a resistant and stable stool, but also visual patterns of the seat that are completely random, yet possess a pleasing look.

It is rewarding to know that recycled thermoplastic can have a new and authentic purpose when applied to furniture. Not only does it offer a different look, but, if designed correctly, these components can offer mechanical and physical superior advantages when compared to wood, metal, or ceramics.

When designing and manufacturing this stool, most of the pre-established eco-design guidelines were followed and applied. Diverse eco-design strategies were applied and focused around the implementation and reutilization of recycled thermoplastics. An eco-design mentality helped to shape and create an idea into a functional and efficient product. No Life Cycle Analysis or detailed evaluation were made to determine the real sustainable efficiency of the product. However, the main purpose was fulfilled; the main component is made from recycled thermoplastic and the entire stool can easily be recycled again.

4. Conclusions

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Society is more worried than ever about the ecosystem health. Given the recent concern with plastic waste accumulation, alternatives on how to create products with recycled plastics are increasing. This ecological trend created new market opportunities. However, this demand on sustainable products is not yet under specified control or regulations; thus, creating confusion and ambiguity on what can be considered sustainable.

In the case of recycled thermoplastics and furniture, this issue is not different. This ecological movement is making the furniture industry implement modern and new products made from recycled goods. Many companies are changing their main materials into recycled composites, this option may be considered a viable "eco-friendly" option. However, there is no point in making a good that uses recycled materials and cannot be recycled again in the future.

With the design and manufacturing of the Gibada stool, it was possible to confirm that recycled HDPE can effectively be used as a main component in a furniture stool. The main objective was fulfilled; the central component of the stool is made from recycled thermoplastic and the entire furniture can easily be recycled again.

The stool developed shows the wide possibilities of products that can be done with recycled thermoplastics, thus, it promotes and raises awareness to the benefits of implementing recycled plastic in furniture design. Its ergonomic and modular design and threaded leg system allows easy assembly/disassembly, storage or transportation; this is suitable for constant reconfiguration of the available space.

Even though no LCA analysis was made to the Gibada stool, it can be considered an eco-efficient piece of furniture. It is composed by two different materials, no harmful or toxic substances were employed, and it can be easily recycled.

All the manufacturing methods in this project were implemented at an experimental level. They may be considered actions of craftsmanship and had no focus towards mass-production. Therefore, a more detailed analysis has to be made considering future manufacturing methods with an industrial focus.

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Developing a Database of Circular Design Open Educational Resources

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Abstract

With the rise, in recent years, of user-generated content and openly available knowledge, many design tools and methods on sustainability and Circular Economy have been developed and self-published online by practitioners and educators. In addition, there are many resources (e.g. policies, reports, tools, etc.) published by non- and intra- governmental organisations with the purpose of promoting sustainable practices and facilitating education for sustainability. While the number of openly available resources rises, these resources often remain out of sight due to the lack of proper documentation and indexing. As part of Circular Design: Learning for Innovative Design for Sustainability (L4IDS) Erasmus+ Knowledge Alliance project, universities, SMEs and design centres from four European regions (i.e. Ireland, Catalunya, the Netherlands and Sweden) have collaborated to develop an Open Educational Resource (OER) Database. This database serves to document and categorise readily-available resources to address this gap. The purpose of the database is to act as a bridge between online resources and practitioners, design educators and researchers, enabling them to find and utilise available tools and methods for both educational and practitioner purposes.

For this purpose, the team initially conducted desk research to find available resources online. A categorisation strategy was suggested based on the other outcomes of the project (i.e. Circular Design Internships for undergraduate students and Professional Development Courses for professionals). The list of resources was then added to, and the categorisations revised, based on feedback and input from the entire project team. OERs were categorised under four main themes - (1) First-timers, (2) Practitioners, (3) Businesses, Services and Policies, and

(4) Design Education – and 16 sub-themes. The database was then incorporated and trialled through four consecutive Circular Design Internships in partner countries as well as through the Professional Development Course conducted in Ireland revealing the strengths as well as limitations of the database in undergraduate design education, professional development and self-learning. This paper presents the development process of the OER Database and its implementation in two different learning programmes. In addition, several gaps in readily- available online resources were identified to promote the future development of freely accessible educational materials by design educators in Europe and beyond. The OER database has the potential to contribute to the dissemination of accessible, readily-available educational tools for sustainability and Circular Economy, and to facilitate collaboration among design educators through open knowledge sharing.

Keywords: Design Education for Sustainability, Circular Economy, Open Educational Resources, Circular Design, professional development

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1. Introduction

Design for sustainability education has become more and more comprehensive over the years, taking into account multi-faceted considerations befitting the complexity of the sustainability issue. While the UN Sustainable Development Goals released back in 2012 provide an overview of this complexity through identifying 17 large problem areas, there are numerous ways design, as a practice, can contribute to this challenge through approaches such as social innovation, product services systems, design for Circular Economy, design for transitions, design for behaviour change, and so on. These approaches, addressing different aspects of sustainability inevitably present different implications in practice. As such what is required are numerous tools and methods continuously being developed by design practitioners, educators and researchers in the pursuit of embedding sustainability considerations into acts of design. In addition, there are many resources (e.g. policies, reports, tools, etc.) – not directly affecting the design practice but relevant - published by non- and intra-governmental organisations with the purpose of promoting sustainable practices and facilitating education for sustainability.

The case for sustainability education

Students, at higher education level, are now demanding that sustainability be integrated into their curricula in ways that not only increase knowledge of the subject but also develop practical skills that are applicable to professional life. The final report from the UN Decade of Sustainability Education (UNESCO, 2014) recommends that new approaches to curriculum reform need to extend beyond conventional institutions and into lifelong learning models for practitioners, professional bodies and community stakeholders. This will capitalise on the growing awareness of, and desire to, integrate sustainability into private businesses in more technical and implementation-driven ways. "Technical 'know-how' will not be sufficient. Skills and capacities for whole- systems approaches, critical thinking, and collaborative problem-solving will also be needed for private-sector transformation" (UNESCO, 2014, p.150). Whilst the integration of sustainability in larger businesses and multinational corporations is underway, the challenge of increasing capacity and training for small, medium and micro enterprises (SMMEs) needs to still be addressed (ibid).

Collating and Organising the Tools for Sustainability

The first stage in the development of the Open Educational Resource (OER) database was to collate the resources available, both online and offline, followed by the task of organising them into a format and structure that was logical and useful for designers. It is crucial that the correct types of supports are available to designers to enable them to undertake more sustainably focused projects (Lofthouse 2006). Widely dispersed tools and materials can often be overwhelming and therefore useless. Sustainability tools must be usable by all designers and not just experts if eco-design and sustainability are to become mainstream (Le Pochat 2006).

Literature does exist on categorising the existing tools for eco-design and sustainability. Rousseaux et.al. (2017) outline the complex and often contradictory process of categorising eco-design tools. They recognise that identifying the most appropriate tool(s) and implementing them can often prove overly complicated and difficult for employees of large companies and SMEs. Often with categorisation, deciding on the categorisation criteria, the tools to include, identifying the intended user and how to implement these tools are the most difficult aspects of the task. Criteria for the selection of tools to use in projects tend to be 'technical, scientific or methodological' (Rousseaux et. al. 2017), based on the format of the tool (database, software, paper, online, interactive etc.) or indeed the usefulness of the tools at a particular stage in the design and development process (Le Pochat 2006).

Previous efforts to organise eco-design tools have resulted in categories such as 1. Analysis (assessment); 2. Prioritisation of improvement; 3. Aid for creativity, and 4. Aid for decision-making (Charter and Tischner 2001). Whereas others have categorised the tools and case study projects using 'use-oriented' classifications: complexity, type and main function (Hernandez-Prado et. al. 2011).

Rousseaux et al. (2017) organise the tools into a tree configuration under two categories: Environmental tools-*where to act;* Improvement tools-*how to act*. Company employees, working across different functions, can access the most appropriate tool for them for either 'how to act' or where to act based on the environmental issue or concern at that time. The tools can serve a functional purpose as well as a social purpose. Functional as a communication tool within the company, to build knowledge and capacity giving employees agency over making decisions and implementing environmental actions, with the social purpose being to increase knowledge and legitimize an *eco-company culture* (ibid).

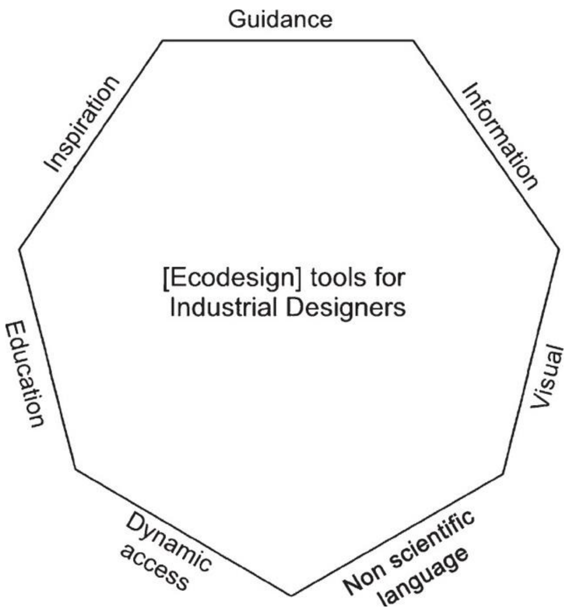

Figure 1. *A holistic framework for Industrial Design focused ecodesign tools (Image from Lofthouse, 2007).*

The third stage in the OER development was to create a user interface that would appeal to designers and ensure an intuitive user experience; essentially combining useful content in a stimulating way are success factors for a design tool. Bakker (1995) and Sherwin's (2000) findings both recognise that eco-design information should be presented visually using case studies and examples. In the *Imagination Information* resource Lofthouse (2007) offers examples of 'successful' projects to demonstrate the potential of eco-design as applied in practice. Through these examples, specific technical information (materials, production techniques), as well as more general information, can be communicated. It is also essential that appropriate information (to design) is pitched at the appropriate levels. High-quality visual communication (images, videos etc.) and interactivity (hyperlinks to other pages, connected topics/themes) were also identified as success factors in appealing to designers and in motivating them to use resources (Figure 1). Combined with this, is a need for a non-technical approach with short pieces of digestible information leading to more in-depth

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information as required and simple guidance for beginners, and legislative requirements (Lofthouse 2007). Considering these factors in the development of the OER database was crucial to its success.

2. Methods

The development of the OER Database is led by the authors, however, information and feedback were collected from the project partners at specified stages. The database was developed with the expert input from lecturers, design practitioners and design association members involved the Circular Design (L4IDS) project, providing expert feedback on various practical and educational needs. While the initial design and structuring of the database were undertaken by the project members, the website development was outsourced. The development of the OER database is undertaken in the following stages:

1. **Scoping:** Understanding the varying needs and levels of knowledge of students, design professionals and educators, as well as the overlap with other outcomes of the Circular Design (L4IDS) project (i.e. Best Practice Publications, Circular Design Internship Programme and Circular Design Professional Development Course),
2. **Identifying categories;** Defining inclusion/exclusion criteria, database categories and sub-categories, and information management of openly available educational resources,
3. **Drafting:** Project partners consisting of educators and practitioners reviewing the initial proposal for OER Database structure and features (e.g. Figure 2), development of the beta version of the database (UX/UI).
4. **Populating the database:** Creating content for the OERs, and publishing a *Call for OERs*, online and through other channels (e.g. flyers in DRS 2018 Conference)
5. **Finalising:** Gathering feedback on the beta version of the database[1], final version of the database.

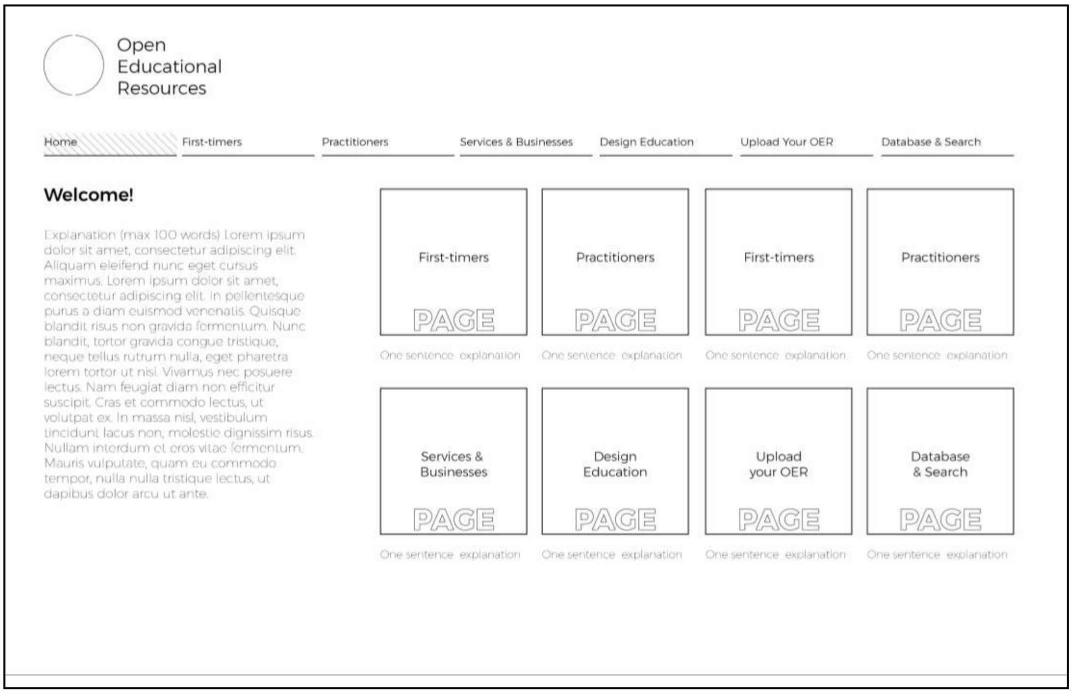

Figure 2. *An initial sketch of the OER database showing the main menu details*

As a result of these steps, an open-access database was launched categorising the open educational resources in a way that would cater to the needs of different audiences. In the following sections, the properties of the database and their reasoning will be explained in further detail.

3. Pooling and Categorising Existing OERs

Searching and identifying OERs was the first step of the database development. The authors, while aware of many online resources through their educational and research experience, adopted a systematic approach to finding existing resources on sustainability and Circular Economy. This was done in three stages:

1. Searching keyword strings in a search engine (i.e. Google) – standalone or with different parameters – and going through a certain amount of search results (approximately 200) for each keyword.
2. Searching organisations' websites for shared OERs, including design-related departments (e.g. Parsons the New School), NGOs (e.g. Ellen MacArthur Foundation, Global Footprint Network, etc.), intra- governmental organisations (e.g. UN, EU) and research project databases (e.g. CORDIS).
3. Incorporating personally known resources, and consulting project partners for further contributions.

The authors needed to identify OER inclusion/exclusion criteria, considering the nature of this database, its purposes and accessibility (Table 1). An initial list of 96 open educational resources was collated according to this list of criteria, following the above-mentioned stages. After a thorough review of these sources, some of the resources were brought together, and some of them were deemed ineligible, reaching a total number of 76 resources to be uploaded to the database.

Table 1. *Inclusion / Exclusion Criteria for OERs*

Include if:	**Exclude if:**
Openly / freely accessible	Behind a paywall
Requires free membership	Can only be accessed through institutional accounts or paid memberships
From a reliable source e.g. institution/company websites, educational blogs, etc.	From an unreliable source e.g. personal blogs, published under nicknames, etc.
One of the following types: Website, Article, Toolkit, Forum / Community, Audio / Video, Reports, Course Material, Databases, Case Studies	One of the following types: Highly technical reports, blog posts, opinion pieces, etc.
Addressing issues around sustainability and circular economy.	Design-related resources not addressing, and with no direct relation to, sustainability and circular economy.
Acceptable quality, assessed through: Shared knowledge & comprehensible delivery	Not acceptable quality

Categorising resources in a meaningful manner in line with different stages and types of design practice was a challenging task. The authors developed the initial OER database structure along with the first Circular Design Internship conducted at the University of Limerick, Ireland, in the Fall of 2017-2018 (for more information, see McMahon & Bakırlıoğlu, 2019; Bakırlıoğlu, McMahon, deEyto & Rio, 2018). The internship aimed at enabling novice designers to gain the skills necessary for designing for circular economy and sustainability, initially starting with defining and scoping the term sustainability and leading to its implications for design and

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innovation, various tools and methods and the different scales (i.e. product to service and systems) to be addressed. Hence, the initial categorisation of resources took place in parallel with the skills development stage of the internship (Table 2).

Table 2. *The categorisation used in the OER Database*

Main Categories	***Brief Explanation***	**Sub-categories (Initial)**	**Sub-categories (Revision)**
First-timers	*for people new to design for sustainability*	Start with the basics	The basics
		Our impact on Earth	Indexes & Reports
		Approaches to Design for Sustainability	Approaches to Design for Sustainability
		Inspirational Examples	Inspirational Examples & Experiments
		Active Communities	-
Practitioners	*for people who want to design for sustainability*	Prepare a Design Brief	Preparing a Design Brief
		Understanding Involved People	Understanding the Context
		Tools for Designing	Tools for Design Practice
		Sustainable Materials & Production Techniques	Materials & Production Techniques
		Best Practice Publications (design-oriented)	Best Practices
		-	Active Communities & Networks
Businesses, Services, Policies	*for people who want to build services & businesses from a design for sustainability*	Making a Business Case	Making a business case for Circular Design
		Assessment of services & businesses	Measuring the effectiveness of Circular Design projects
		Regulations (EU & country specific)	Regulations & Policies related to Circular Design
		Best Practice Publications (service/business-oriented)	Best Practices / Services and Businesses
Design Education	*for educators to teach about design for sustainability*	Design Projects	Educational Design Projects
		Theoretical Courses	Mixed Content Courses

At the *drafting* stage, this categorisation, along with the initial sketches of the website, was presented to the project partners to gather their feedback in the form of a group discussion during the first annual project meeting held in October 2017, in Limerick, Ireland. The academic and practitioner participants raised several suggestions for, and reservations against, the categorisation and the website structure, summarised as follows:

- **Feedback (F):** Some of the resources available online can be rather comprehensive and can fall under several categories.
  Decision (D): A knowledgebase structure that allows assigning multiple categories to a single OER page was adopted.

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- **F:** The names of the categories are confusing, or do not really reflect their content. In addition, the names should also be compatible with the Professional Development Course developed under the Circular Design (L4IDS) project.

  D: The names of the sub-categories were revised, as presented in *Sub-categories (Revision) column of Table 2*.

- **F:** There should be an additional categorization reflecting the level of complexity of the OERs (e.g. level of knowledge, amount of content, the time required to go through, etc.)

  D: A simple, three-level categorisation was adopted, namely *(1) Beginner*, *(2) Intermediate* and *(3) Advanced*. OERs in the *beginner* category does not require design practice experience or academic knowledge, while the ones in the *advanced* category require a thorough knowledge and understanding of the design field.

- **F:** A user account should not be mandatory to reach the database and its contents.

  D: The database is freely accessible to everyone; however, commenting is restricted only to registered users for security reasons.

The above-mentioned comments were the most prominent ones, however, there were other comments on e.g. the aesthetic quality of the database webpage or small UX details to enhance ease of use. The decisions were reflected in the website design and a Beta version was developed and released in February 2018.

4. Preparing OER content and populating the database

The initial purpose of the Circular Design OER database was to make existing resources accessible, hence the content for each OER page was prepared to give an introduction and a link to the original content, in addition to crediting the creator/author of the OER, as well as their affiliation and date. However, the page content also needs to guide the users about the extent of the OER or to reflect the potential uses for it. Nearly all OERs included and categorised in the database has their own websites or platforms with detailed explanations of them, which the authors decided to use excerpts from. In some cases, if the OER content is more complex or simply long, a list of contents or topics was added as well (Figure 3).

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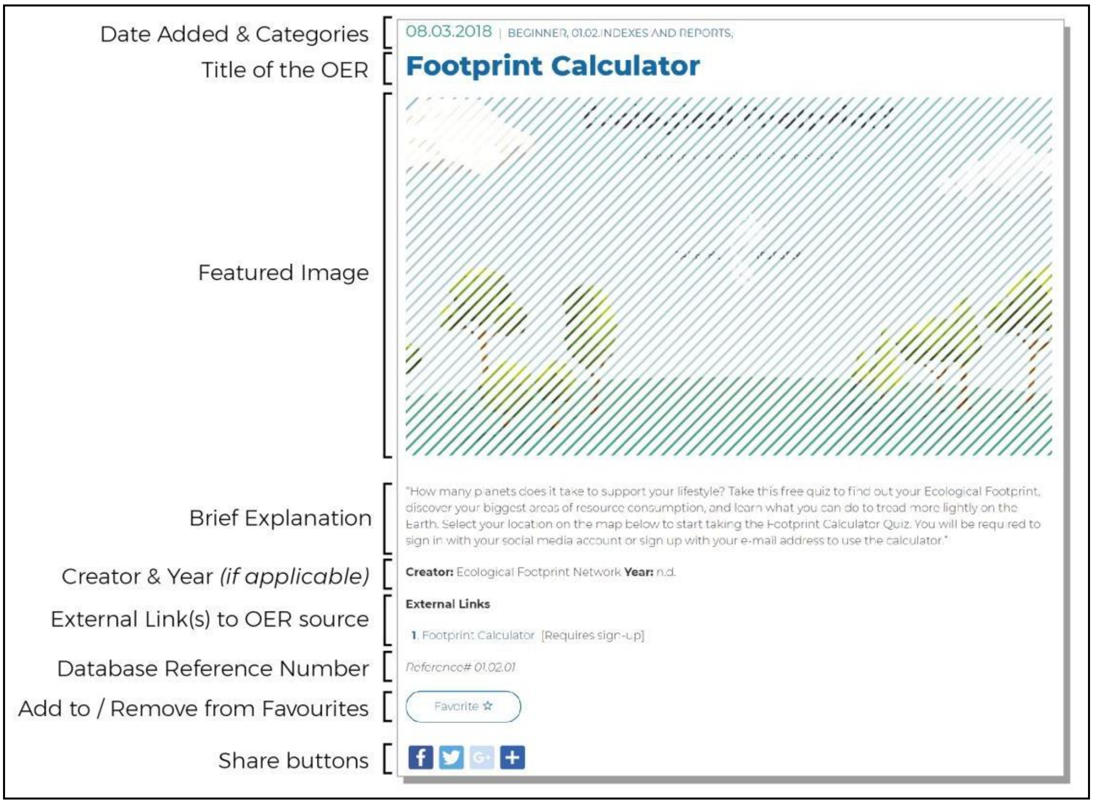
Figure 3. *An example of OER pages, showing the layout and content*



The authors prepared the content for each OER page using the layout presented in Figure 3. This involved finding appropriate excerpts from OERs' original sources and finding suitable images shared through Creative Commons license or seeking permission to use certain images on the website. A database reference number was assigned to each page to ensure the content can be identified in a separate file kept by the authors. Although the page layout does not show any keywords, each OER page was given a few keywords to facilitate meaningful in-site search function, in addition to the database categories and OER titles. These keywords included the names of individual creators and/or their affiliations, other affiliated parties, and alternative names for the sources – e.g. 'Agenda 21' keyword for Rio Declaration on Environment and Development, UNCED 2012 Report.

5. Testing the content and the database

The website was populated by 76 OERs and ready for pilot testing by May 2018. The usability of the website was tested among the project partners (12 individuals in total provided feedback). The testing protocol was simple: (1) a set of tasks was generated and distributed among partners, and (2) participants filled in a feedback form according to those tasks. The tasks were as follows:

1. Create an account
2. Explore the OERs – go through categories, explore the content of several OERs
3. Save as favourite at least one of the posts on their profile
4. Leave a comment
5. If there is an OER they want to share, use the *Upload Your OER* form.

6. *Any other task they might want to undertake.*

According to the pilot testing outcomes, several bugs were identified as well as some suggestions for UX design improvements. These suggestions included the way categories are represented, the flow of navigation among categories and the login and profile page for accounts. These bugs and suggestions are being addressed at the time of writing this paper.

The *content* of the database was utilised in four Circular Design Internships conducted at project partner HEIs in Ireland, Catalunya, the Netherlands and Sweden. Since the OER database website was not properly populated until the end of the second internship in Catalunya (May 2018), the OERs were initially incorporated into the first two internships through a mock-up database created with shared cloud folders and spreadsheets. The database was online as a Beta release for the third and fourth internships, which allowed interns to explore the website and provide feedback. Structured group discussions were held throughout all internships, and the OERs included in the database, their content and their effects on the design processes were also queried during these group discussions. The data gathered from those internships, as well as internship coordinators' observations, can be summarised as follows:

- *Promoting self-learning for interns:* The interns were able to explore various state-of-the-art tools and methods focused on sustainability and CE through the OER database. They needed to evaluate these resources according to the project needs and their capabilities and to decide on the set of tools they would utilise. Accessibility to a wide range of tools categorised in a way that allows them to find relevant ones empowered the interns, strengthening the previous decisions to divide the resources into categories and sub-categories. However, picking and choosing tools and methods was considered time-consuming as well, because they needed to review the OERs in detail before finally choosing the most appropriate one(s).
- *Ease of accessibility in an educational context:* The database as a sharing platform enabled better communication amongst educators, students/interns and external collaborators. In addition to providing a wide selection of tools, methods and resources about sustainability and CE, it also constitutes reference material for communication.
- *A dataset showing the lack of tools, methods and/or resources:* While there are 76 OERs on the database, both interns and educators noticed a lack of resources supporting certain stages of the design process. Examples of this can be 'Preparing a Design Brief' sub-category which only has one tool focusing on certain aspects of CE, and 'Educational Design Project' sub-category which does not have any cases, educational project briefs, etc. Similarly, the level of complexity of some OERs belonging to a category can be discouraging – thus, not helpful – for the interns. An example of this can be the sub-category of 'Materials & Production Techniques' with several detailed material and production technique databases, which may prove to be intimidating for the interns.

In order to keep the database up-to-date and inclusive, as well as to address the final point in the above list, the authors created and embedded an online form for practitioners and educators to upload their own or others' online resources. The form asks for the content of an OER page (see Figure 3), and follows the below steps:

1. Choose between uploading "your own" or "a third party's" online resource
2. General information about the OER and its creator(s). This includes the name of the OER, the year

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it was created, name of the creators & their affiliations.

3. Main and sub-category for the resource.
4. A brief description and keywords
5. Link to the OER material or website.

The uploaded resources are reviewed by the database administrators to ensure that they fit the inclusion/exclusion criteria (see Table 1), selected main and sub-category and any additional categories. The uploaders are notified when (and if) their resource is published on the OER database.

6. Discussion & Conclusions

The purpose of the Circular Design OER database is to act as a bridge between online resources and practitioners, design educators and researchers. This enables key stakeholders to find and utilise available tools and methods for both educational and practitioner purposes through documenting and categorising readily-available resources. The authors agree with Le Pochat (2006) that the abundance of thorough and varied sustainability and eco-design tools does not readily enable design practitioners to incorporate sustainability concerns and considerations in their practice. Hence, Circular Design OER database presents 76 OERs under four main categories that are identified according to knowledge/skills development and self-learning for design professionals and design educators, and

16 sub-categories addressing different stages of the design practice in a way similar to the use-oriented categorisation suggested by Hernandez-Prado *et al*. (2011). The database was integrated into the implementation of Circular Design Internships in four European countries and was utilised in the development of Circular Design Professional Development Course. The database is online as a Beta release at the time of writing this article, and the final version is expected to be online in the last quarter of 2019.

The database in its current form presents potential to be utilised in other contexts. As an example, the authors integrated the database into their Design for Sustainability undergraduate module, specifying categories and sub- categories to match the topic of each lecture. The purpose was to guide students to explore existing approaches, methods and tools for themselves and to define their own practical approach to design for sustainability and CE. From the educators' perspective, the database constitutes a readily-available resource to create and/or improve their modules and courses. For professional development, it is an always accessible reference point for life-long learning.

While developing the OER database and integrating it into different educational programmes and modules, the authors identified that there are some outstanding topics that still lack open-source resources. For some sub-categories, the available OERs require expert knowledge to utilise and they can too complex to incorporate into the design practice or education. Hence, the authors would like to invite design educators/researchers to contribute to the dissemination and wide-spread adoption of sustainable design practices by developing openly and freely accessible tools and resources applicable for design education and/or professional design practice. The Circular Design OER Database has a continuous 'Call for OERs' and can host these resources.

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Notes:

1. At the time of writing this paper, the OER Database is published as beta and can be accessed through this link: http://circulardesigneurope.eu/oer/. The final version will be released in the last quarter of 2019 and will be accessible through the same link.

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CE Designer: A tool to support learning and applying circular design

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Abstract

This paper starts by exploring the role of design in circular economy and presents an overview of circular design strategies published in the literature; the state of the art is that they tend to focus on product to the detriment of services; they overlook the materials and energy efficiency; and they do not include the social dimension of sustainability in line with a conceptualization of circular economy that focuses on ecological renewal and reduction of finite resource use. In order to overcome these shortfalls, a new tool, "CE Designer", was developed in the context of the Knowledge Alliance on Product-Service Development towards Circular Economy and Sustainability in Higher Education (KATCH_e). This is a 3-year EU funded project that was launched in January 2017 and is part of the ERASMUS+ programme of Knowledge Alliances, aiming to address the challenge of reinforcing the skills and competences in the field of product-service development for the circular economy and sustainability, with a particular focus on the construction and furniture sectors. In this context, a set of training materials and practical tools was developed and implemented in Portugal, Spain, Austria and Denmark, in the contexts of higher education institutions, company-oriented courses and in-company projects. The "CE Designer" checklists are a semi-quantitative tool for prioritization, assessment and idea finding of circular solutions for product and/or service (re)design. They are organized according to eight strategies that address the most relevant issues a design team needs to consider in the development process of new products or services to support the transition to a more circular and sustainable society. The stages of the "Value Hill" as proposed by Achterberg et al. (2016) provide the framework to organise the eight strategies. The use of the "CE Designer" starts with a prioritization of the most promising design strategies for a given situation; next, a semi-quantitative evaluation of a reference product or service, according to a number of criteria within the chosen circular design strategies, allows for (i) establishing its circularity and sustainability profile and (ii) identifying immediate improvement ideas and opportunities for a new product or product-service combination. Undergoing a second evaluation of a new solution, allows for a comparison with the reference product or product-service and an easy visualization of the results achieved.

Keywords: Circular Economy, Circular Design, Tools, Strategies, Practice

1. Introduction

This paper presents the CE Designer, a web tool developed within the European Erasmus+ project KATCH_e: "Knowledge Alliance on Product-Service Development towards Circular Economy and Sustainability and Higher Education". CE Designer belongs to set of training materials and practical tools developed and implemented in Portugal, Spain, Austria and Denmark, targeting higher education institutions, company-oriented courses and in- company projects.

The aim of the CE Designer is to support circular product and/or service (re)design through the use of checklists for prioritization, assessment and idea finding. The CE Designer complements two other web tools developed within KATCH_e: the CE Strategist and the CE Analyst. The CE Strategist helps the user identify circular business opportunities and provides ideas and inspiration along the process of defining a circular business model, using the structure of the well-known Business Model Canvas (Osterwalder & Pigneur 2013). The CE Analyst quantifies the potential improvements of the environmental profile of a given "linear" product, when different circular scenarios (such as share, repair, and reuse) are applied.

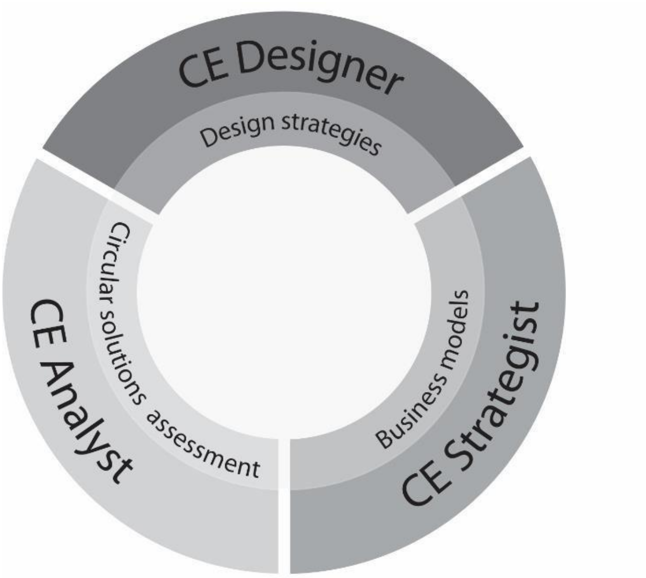

***Figure 1**. The KATCH_e tool kit for design, business development and environmental assessment of circular solutions*

The three tools form a coherent set that have been tested in the target sectors of the project (construction products and furniture) but are applicable to other types of consumer goods. They will be available at www.katche.eu/circular-economy/training-materials/.

2. Background: circular design strategies

2.1 Design and the circular economy

There have been attempts to distinguish between the traditional design practice, ecodesign ("systematic integration of environmental aspects into product design with the aim to improve the environmental performance of the product throughout its whole life cycle" (EC 2009) and design for a circular economy.

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Such distinction is necessary because it is often said and written that circular economy and circular design are simply new designations to practices that have been used for decades, such as recycling and design for recycling. These statements miss the essence of design for a circular economy. Hollander et al. (2017) highlighted that in ecodesign, the practice is to analyse the negative environmental impacts of products theroughout the life cycle and attempt to minimize or eliminate them in what they call a "relative" or "less bad" approach; in a CE, waste no longer exists – theoretically, since there is always some dissipation of materials –, but the aim is zero waste. There is a fundamental difference here, since the goal of a closed loop system often calls for innovative solutions that would not be otherwise thought of. In a circular economy, designers need to have a material flow perspective, meaning that, the resources that enter the system, have to remain accounted for all times, before, during, and after the functional life as useful products (Hollander et al., 2017).

Given that the design of a product directly influences the way a value chain will be managed, building circular, globally sustainable value chains inevitably signifies a fundamental change in the practice of design. A variety of new capabilities are key to design for a sustainable future; these range from a deeper knowledge of material composition to a rich understanding of social behaviour (De los Rios and Charnley, 2017).

In the traditional practice, the design activities have a stronger focus on products, but their role is evolving to a more holistic approach. The power of design lies on its ability to ask fundamental questions, such as: What is the real purpose of this product? Which is the need that this product fulfils? Are there other solutions to respond to such need, e.g. through a service? Is it possible to increase the well-being and happiness through this design? Does this design have a negative impact on the environment? A zero impact one? A positive one, contributing to the regeneration of ecosystems? How about the impacts on the society? (De Groene Zaak and Ethica, 2015).

CE is about "maintaining the function and value of products, components, and materials at the highest possible level and extend their lifespan". The right combinations of product and service design strategies supports circular economy by (Bocken et al., 2016):

- Closing resource flows: through recycling, the loop between post-use and production is closed, resulting in a circular flow of resources
- Slowing resource flows: the utilization period of products is extended and/or intensified, resulting in a slowdown of the flow of resources
- Narrowing flows: using fewer resources per product or service unit.

The KATCH_e project proposes to adopt an integrative approach to the concept and practice of design for the circular economy. Unlike most publications in the field, that focus on slowing and closing resource loops (and disregard the dimension of narrowing loops due to the fact that it applies also to a linear model) and do not consider the social dimension of sustainability, the KATCH_e project adopted the following definition:

Design for a circular economy is a product-service design and development that replaces conventional end-of- life concept by closing, slowing and narrowing the resource flows in production, distribution and consumption processes. It is enabled by innovation and novel business models and aims to accomplish *sustainable development through supporting ecosystem functioning and human well-being, and through responsible production and consumption.*

When it comes to product and service design, what do "slowing loops", "closing loops" and "narrowing loops" mean? Table 1 presents examples of design approaches to make products more durable, to avoid that they become waste and to increase the efficiency and the effectiveness of resources.

***Table 1**: Products and services for the circular economy - adapted from Bocken at al. (2016); BSI (2017); Tukker (2004)*

Product design approaches to slow loops = Design for durability
— To design long-life products — To foster a strong product-user relationship — To produce resistant, easy to maintain and repairable products — To use modularity, to allow the upgrading and adaptation of products — To develop services that support the life extension of the product — To fulfil the user needs with services
Services to slow loops = product-oriented, use-oriented and result-oriented
— Maintenance, repairing, reuse services that extend the lifetime of products (product-oriented) — Sharing, leasing and renting are services that provide the capability to satisfy user expectations without needing to own physical products (use-oriented, sharing economy, "from consumer to the use") — In services that deliver performance, the client or consumer is only interested in the result and not at all in the product or technology behind it (result-oriented)
Product design approaches to close loops = Design for recycling
— To develop products in such way that the materials can be continuously and safely recycled into new materials and products — To use safe and healthy materials for those products that are consumed or worn during use, and thus create food for the natural systems — To make it easy to dis- and reassemble products
Services to close loops = reverse logistics

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— Collection and sourcing of otherwise "wasted" materials or resources to turn them into new forms of value such as reuse, remanufacturing or recycling.

Product design approaches to narrow loops = Design for resource conservation
— To use a preventive approach in which products and services are designed so that resources use is minimized in the whole life cycle — In addition to quantity, to choose more sustainable materials and energy sources when designing a product or a service
Services to narrow loops = dematerialization
— Delivery of a function with no or reduced requirement for materials; digitalization is a very strong enabler for dematerialization.

2.2 Overview of circular design strategies

An exhaustive analysis was performed in the literature to identify design strategies for circular economy and sustainability. The main authors considered and the strategies they advocate are shown in table 2.

Table 2. *Overview of literature review on strategies for circular economy*

Author	**Strategies**
Bocken (2016)	DESIGN STRATEGIES TO SLOW LOOPS: Designing long-life products — Design for attachment and trust — Design for reliability and durability Design for product-life extension — Design for ease of maintenance and repair — Design for upgradability and adaptability — Design for standardization and compatibility — Design for dis- and reassembly DESIGN STRATEGIES TO CLOSE LOOPS: — Design for a technological cycle — Design for a biological cycle — Design for dis- and reassembly
Devadula & Chakrabarti (2015)	DESIGNING-OUT WASTE — Design for durability (materials and components) — Design for standardization and compatibility — Design for remanufacturing — Design for disassemblability and assemblability (repair) — Design for disassemblability and assemblability (re-furbish) — Design for recycling — Design for materials sustainability

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den Hollander (2017)	DESIGN FOR RECYCLING DESIGN FOR PRODUCT INTEGRITY: — Design for long use – Design for physical durability – Design for emotional durability — Design approaches for extended use – Design for maintenance – Design for upgrading — Design approaches for recovery – Design for recontextualising – Design for repair – Design for refurbishment – Design for remanufacture
Gerritsen (2015)	— Design for attachment & trust — Design for durability. — Design for standardization and compatibility — Design for maintenance and repair — Design for disassembled and reassembled. — Design for updatability and adaptability
van den Berg and Bakker (2015)	— Design for future proof (last long, use long) — Design for disassembly: – Design for maintenance – Design for remake – Design for recycling
Bakker et al (2014)	— Design for attachment and trust — Design for durability — Design for standartisation and compatibility — Design for ease of maintenance and repair — Design for upgradability and adaptability — Design for dis- and reassembly
Dunmade (2013)	— Design for multi-lifecycle: – Design for assembly and disassembly – Design for simplicity – Design for modularity – Design to cost – Design for materials – Design for use and reuse – Design for manufacturability – Design for packaging

Table 2 shows that there are some common strategies, related to keeping products as long as possible while maintaining functionality and performance (van den Berg & Bakker 2015; Bocken, 2016) using the technical characteristics of the products (reliability and durability) or the ability to restore their initial performance through repair or maintenance interventions. On the other hand, some authors focus on the emotional link between the user and the product through adaptation and/or customization (Bakker et al 2014; Gerritsen 2015; Bocken, 2016; den Hollander, 2017).

Dunmade (2013) proposed design strategies to reduce material consumption by promoting the reuse of materials already in circulation in different streams, giving rise to multiple life cycles.

The strategies should be implemented in an integrated and holistic approach in order to increase the circularity and sustainability potential of products and resources maintaining them in circular loops and eliminating the

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waste production in all stages of the life cycle.

3. KATCH_e circular design strategies

The KATCH_e design strategies follow the definition of design for a CE adopted in the project and therefore their main features are:

- They are in line with the project's understanding that the circularity concept needs to be placed within the overall goal of sustainable development. Therefore, there are social sustainability criteria integrated into the different strategies;
- They are organized according to the three main types of loops in CE as presented in section 2.1: slowing resource loops, where the key idea is durability; and closing resource loops, where the key idea is recycling; such strategies ought to be combined with those related to narrowing resource loops (that includes efficiency and has a life cycle perspective), which are usually not associated with the CE concept and understanding, but need to be considered so that solutions are truly circular and efficient;
- They include a strategy related to energy (with criteria concerning efficiency and the use of renewable energy sources, since according to Ayres (1994), sustainability requires that most of the energy inputs to the economy should come from renewable sources);
- They should be looked at holistically, which means that rather than concentrating on a single strategy, in practice, designers should consider the different strategies, their interdependence, and complementarity;
- None of the strategies are a guarantee for sustainability; the implementation of a specific strategy or a combination of strategies can have negative externalities and trade-offs that need to be evaluated and tackled using life cycle thinking and solved preferably through innovation;
- These strategies concern both product design and service design and are mutually supportive; often, business models are mentioned because circular product and service design is intertwined with business models that companies adopt to put them into the market;

It should be noted that the strategies related to narrowing loops stem from the eco-efficiency paradigm and should always be used in combination with those which slow and close loops, as they are complementary. In other words, it does not make sense to design a long life product without caring for the energy and materials (including water) sustainability along the life cycle (Bocken 2016) . This idea is illustrated in table 3, where the proposed KATCH_e design strategies are distributed along a simplified version of the products' life cycle, also know as the "Value Hill" (Achterberg et al., 2016): (i) Uphill - before use (encompassing extraction of raw materials, manufacturing, assembly and retail), (ii) Tophill - during use and (iii) Downhill - after use (including reuse, refurbish, remanufacture and recycling – and eventually final disposal). The table shows the most direct relationship, but one should keep in mind that potentially the entire life cycle is affected by each of the strategies – for instance, moving from a product to a service approach, although it concerns the use phase because the use/consumption model is changed, may lead to less products needed for the same function, which means fewer resources extracted and processed, less waste, etc.

Table 3: *KATCH_e design strategies for a circular economy, organized according to resource loops and phases of the life cycle they relate to value hill*

KATCH_e design strategies for a circular economy			
Value hill[1] Resource loops[2]	Uphill 	Tophill 	Downhill 
Slowing loops		— Design of long-life products (A) — Design for product-life extension (A) — Design of product-oriented services (B) — Design of use-oriented or result-oriented services (B)	
Closing loops			— Design for recycling (A) — Design for remanufacturing (A)
Narrowing loops	— Design for materials sustainability (A) — Design for energy sustainability(A)		

[1]According to Achterberg et al. (2016)
[2]According to the framework of narrowing, slowing and closing resource loops (Bocken 2016)
A – Product design
B – Service design

In tables 4 and 5 the KATCH_e strategies and respective criteria are presented. Each strategy includes a set of relevant criteria that designers, product developers and companies should analyse and implement as much as possible in order to develop new circular products and services. The strategies are divided in two groups. Table 1 includes the optional strategies that the design team should analyse and select according with the specificities of the project, the product and the company policy. The second group includes the two strategies considered mandatory. In this case, to guarantee that the new solutions are resource efficient and have a low environmental impact, these strategies and criteria must be considered in the development process.

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Table 4. *Overview of the optional KATCH_e circular design strategies*

Circular design strategy	**Description**	**Assessment criteria**	**Value hill[1]**	**Resource loops[2]**
Design of long-life products	Designing long-life products is concerned with ensuring a long utilization period of products through features that enable products to serve their originally planned functions over a longer period of time without loss of performance. This is the counter strategy to the implanted programmed obsolescence, in which the products are designed to lose part or all of their performance elements after a specific period	— Strong product-user relation — Durable and wear resistant materials and components — Timeless and customized design — Reliability — Lifespan information to clients/consumers — User-friendliness	Tophill	Slowing
Design for product-life extension	Product life extension is concerned with an increase in the use period of products, which results in a slowdown of the flow of materials through the economy. It concerns maintenance, repair and upgrading or a combination of these. Service loops to extend the life time are closely related to this strategy and addressed in strategy "Design of product life extension services".	— Easy replacement of components — Aesthetic and/or technical upgradeability — Durable and wear resistant materials and components — Use of modular solutions — Simplified product architecture — Choice of tools needed for dis- and reassembly — Minimize connecting elements — Facilitate access and detection of connecting elements — Standard connection elements	Tophill	Slowing
Design of product-oriented services	This strategy includes different types of services that prolong the lifetime of products. They concern consumer products as well as business-to-business situations. The business model is still mainly based on the sales of products, but some extra services are added. The sustainability potential of these services depends on the actual increase in the lifetime of the goods. It is important to note that the goods involved in providing these services should follow the strategies and criteria here proposed for circular product design.	— Geographic accessibility — Variety of offers — Customer satisfaction — Added-value (for customers) — Employment creation and good working conditions — Transportation sustainability — Involvement and promotion of local community	Tophill	Slowing

Design of use- or result-oriented services	In this strategy, the key word is "ownership". The provider retains the ownership of the product and makes it accessible to the clients (individuals or organizations) through different business models like leasing, renting, sharing, pooling, etc. (access-oriented services). Alternatively, the provider makes a result available to the user and in this case the relationship with a pre-determined product is weaker (result-oriented services). Here, the client and provider agree on a result – the way of achieving such result is more open than in the services and therefore the potential of finding radically new and more sustainable solutions is higher.	— Accessibility — Influence in product design — Impact of the service in resources use intensity — Existence of easy and affordable ICT — Customer satisfaction — Added-value (for customers) — Transportation sustainability — Involvement and promotion of local community	Tophill	Slowing
Design for recycling	The objective of this strategy is to develop products in such a way that the materials ("technical nutrients") can be continuously and safely recycled into new materials and products. Designers must understand the process and the conditions for an efficient and quality recycling, resulting in quality materials that can be used as valuable input material in the product or service cycle.	— Use of recyclable materials — Choice and variety of materials for easy recycling — Marking materials for recycling — Easy separation of technological from biological materials — Minimize connecting elements — Facilitate access and detection of connecting elements — Standard connection elements — Avoid the use of dangerous tools and processes	Donwhill	Closing
Design for remanufacturing	Design for remanufacturing is a combination of design strategies whereby a product is designed to facilitate remanufacture. Remanufacture returns a used product to a "like-new condition"; it is a process of recapturing the value of the material when a product was first manufactured. Remanufacture results in the reduction of energy and material consumption, and production cost reductions, allowing the manufacturer to increase the productivity as well as the profitability in the business.	— Technology integration/stable technologies over lifetime — Use of modular solutions — Existence of a take back programme — Optimize reverse logistics (RL) network design and involve the supply chain in RL planning — Durable and wear resistant materials and components — Simplified product architecture — Minimize connecting elements — Facilitate access and detection of connecting elements — Standard connection elements — Employment creation and good working conditions	Downhill	Closing

[1]*According to Achterberg et al. (2016)*
[2]*According to the framework of narrowing, slowing and closing resource loops (Bocken 2016)*

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Table 5. *Overview of the KATCH_e mandatory circular design strategies and criteria*

Circular design strategy	Description	Assessment criteria	Value hill[1]	Resource loops[2]
Design for materials sustainability	Resource efficiency means using the Earth's limited resources in a sustainable manner while minimizing impacts on the environment. It allows us to create more with less and to deliver greater value with less input. A reduction of the quantity of materials used in a product or service is possible by implementing efficient strategies in product and service design. The selection of materials and component is a key element in the definition of the potential impact of a product or a service. In the design phase, the design teams can choose materials and components with lower impact by itself, or that have a positive influence on the product or service systems.	— Optimize products' design (shape, size, weight, etc.) to reduce material consumption — Avoid consumable materials in the use phase — Use of recycled materials — Eliminate the use of toxic materials in the product — Avoid the use of non-renewable materials in the product — Use of locally produced raw materials and components — Avoid the use of scarce and/or critical materials and promote the use of abundant materials — Use of raw materials and components from suppliers with good social responsibility practices — Information on product sustainability to consumers — Influence sustainable consumer behavior regarding materials consumption	Uphill Tophill	Narrowing
Design for energy sustainability	Product design should take into account the energy that the product will need to meet user needs, taking the whole life cycle into account. For energy-using products (e.g. electronics, cars, lighting), the use phase may be the most important one; however, for many other non-energy consuming products (such as furniture or packaging), the manufacturing phase can represent a significant portion of energy consumption. In service design, on the other hand, the transportation activities may take a very significant role when it comes to energy, since many services require a lot of transport. This strategy thus encompasses energy efficiency, the use of solutions that incorporate renewable energy and also the consumption of energy related to transport	— Reduce energy consumption in production — Reduce energy consumption in use — Reduce energy consumption in transport — Energy plus — Replace non-renewable by renewable energy — Use low embodied energy materials — Information on energy consumption to clients/consumers — Influence sustainable consumer behavior regarding energy consumption	Uphill Tophill	Narrowing

[1]*According to Achterberg et al. (2016)*
[2]*According to the framework of narrowing, slowing and closing resource loops (Bocken 2016)*

4. CE designer tool

4.1 What is the tool for?

The tool was developed to facilitate and promote the integration of circular economy strategies and criteria into the design and development process. Its concept and architecture were developed to meet the needs of design practice with a reasonable ratio between the effort/data required to fill it and the results obtained, providing to the user a set of information that can guide the improvement efforts to highlight the relevant aspects from the perspectives of circularity and sustainability and thereby obtain consistently, verifiably and useful information for its design decision-making process.

The CE Designer is a semi-quantitative tool for prioritization, assessment and idea finding of circular solutions for product and/or service (re)design. The assessment procedure and concepts are organized according to the eight strategies that address the most relevant issues a design team needs to consider in the development process of new products or services to support the transition to a circular system.

4.2 How is the tool used?

Based on the literature review, as well as the feedback received from the various stakeholders, the use of the tool follows six fundamental steps, as shown in figure 3, which are interlinked with the design process.

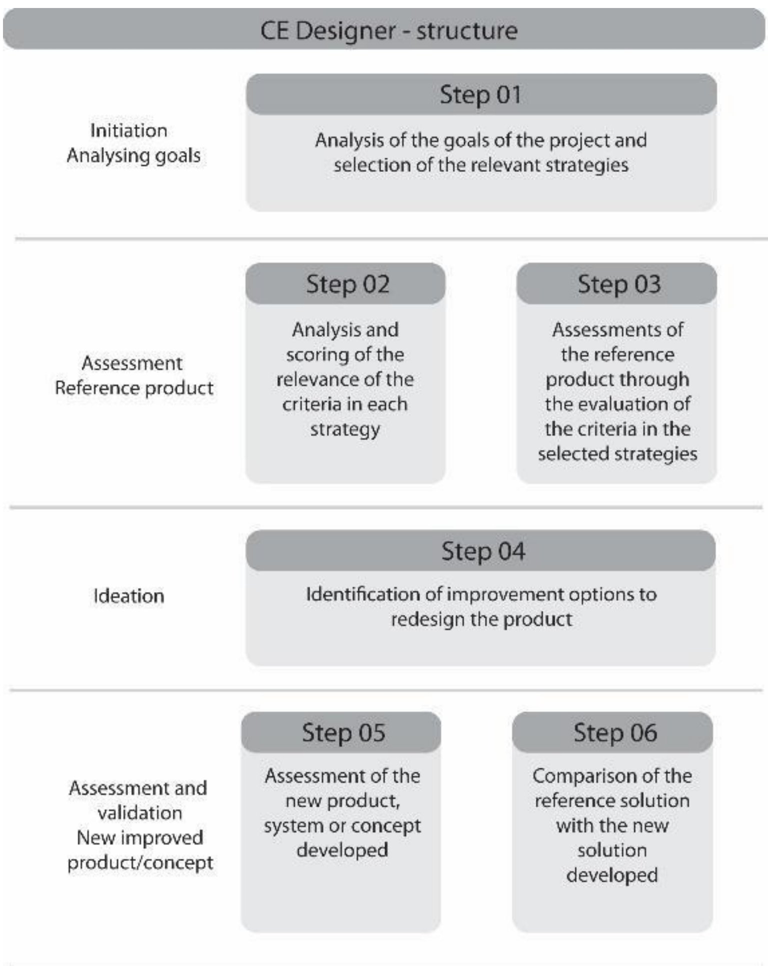

Figure 3. *The KATCH_e CE designer tool – Structure*

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In the first step, the user should prioritize the six optional strategies through a simple evaluation according to the requirements of the particular project, the company, its business strategy, etc. The evaluation will allow the identification of the strategies that are relevant to be considered in the assessment. The two strategies "Design for materials sustainability" and "Design for energy sustainability" are considered mandatory and are always pre- selected in the tool in line with the idea that circular olutions must be resource and energy efficient.

The assessment of the reference product starts in step two. At this stage, in each of the selected strategies, the user should analyse and indicate the relative importance of each criterion because there can be different levels of importance according to the specificities of each project. By default, all are rated as very important.

In the third step the user evaluates each applicable criterion with the ABCD scoring system (figure 2). For each scoring level, the user has three questions or allegations and he/she should identify which one better reflects the product under evaluation. As mentioned previously, the "A" rated allegation or question means that the reference product is performing well in regard to the criterion, "B" means that the product performance is medium, and often there are some opportunities to improve, and "C" describes a product with a lower performance. In this case, usually a hotspot is identified which offers usually a good opportunity to improve in the new product or service. In the scoring area there is also an option "D" for the situations in which the criterion is not applicable. The weighted sum of the performance of all criteria results in the final score of the strategy for the product/service.

Being a subjective assessment, which is based on the perception and knowledge of the development team, the users should have a good knowledge of the sustainability profile of the reference product or service along the life cycle, or be provided with such information. Previous knowledge about CE and the strategies is recommended in order to attain a more reliable assessment.

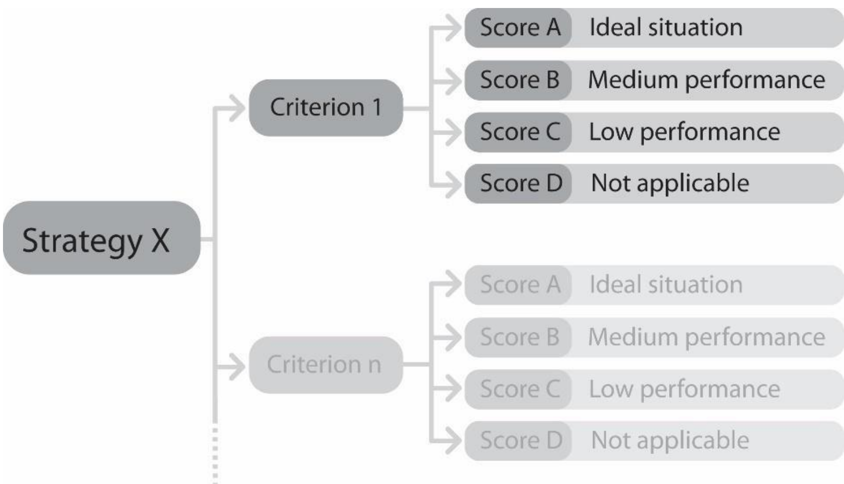

Figure 2. *KATCH_e CE designer tool – scoring procedure concept*

After the evaluation, the user, in a fourth step, inserts improvement ideas or measures linked to each criterion. These ideas can be used in a brainstorming session or other creativity process after filling the tool for the reference product or service. After the filling in of all relevant information, the user can go the results spreadsheet, in which a chart with the score of the strategies is displayed, plus the information resulting from the analysis. This information may then be used to support creativity sessions to define a new concepts for products and/or a services.

Following the concept development phase the new product and/or service, or new concept, is analysed according to the same procedure described in step 3. This will allow a comparison between the reference situation and the new one, which is displayed graphically in the results which is the step 6. In this phase the user can see and demonstrate how the sustainability and circularity performance of the new solution changed.

4.3 What results can be expected?

- A prioritization of applicable design strategies for a more circular and sustainable product/ service;
- The analysis of a reference product or service according to the selected circular design strategies;
- Immediate improvement ideas and opportunities, through the reflection and assessment of each strategy and related criteria;
- Background information for a brainstorming or other creativity session;
- A graphic comparison between the reference product or service and the new one(s). With this feature, the team can communicate where and how the new solution performs better.

Figure 4 is a demonstrative example of the results attained with the tool. Using the information, the design team can easily demonstrate the improved performance of the new product by strategy.

***Figure 4**. CE Designer - example of the results*

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5. Test and validation of the concept and content of the CE Designer

In order to guarantee the quality, adequacy and applicability of the KATCH_e materials it was important to involve a wide group of stakeholders in the process. The test phase delivered valuable feedback on meeting the needs of the users.

In the CE Designer, the various tests carried out in academia and business sectors allowed the improvement of the final tool in some structural aspects and others for providing a better understanding of the interface and content.

Thus, within the development and testing process it was concluded that two of the initial strategies, namely design for reverse logistics and design for disassembly, were better conceptualized as preconditions for other service- oriented design strategies. However, the criteria that characterized them were integrated into the other existing related strategies

Another important aspect to be considered was that in a first version of the tool there was a hierarchy of the different strategies. It was concluded that this weighting at an early stage generates some entropy, so it was decided only to select the applicability of the strategies to evaluate a particular product. There was also a need to better explain some of the criteria, while some are self-explanatory by their designation, others needed to be better explained for a correct interpretation and evaluation.

During the test and validation initiatives such as the pilots developed in the partner companies, workshops, seminars, presentations etc, carried out in all partner countries, additional and valuable feedback had been gathered from colleagues or external experts in the field of life cycle assessment, ecology, architecture, sustainable design, design, and other fields via bilateral exchange with national stakeholders. The feedback from experts, practitioners, trainers, etc was collected and implemented through a specific procedure developed within the project allowing the development of a tool that meets the needs faced by the design practice in the transition to a more circular and sustainable economy.

6. Conclusions

The CE designer tool, offering a systematic and integrated approach in the evaluation of the design and circularity performance of a product or service in a circularity and sustainability perspective, was developed by a partnership of experts in design, sustainability and circular economy with a collaboration of national stakeholders networks established in the partner country. This close relation of research institutes, academia, companies and other stakeholders through an established plan of co-development supported by a defined procedure to collect and implement the feedback from several test and validation activities allowed the development of a tool that mets the needs of the design practice for a circular economy.

Currently, circular economy tools are emerging in line with the increasing engagement of governments, institutions and professionals and the potential to attain a more sustainable and circular economy seems to be very promising, however, many of the existing available tools and resources tend to focus on product to the detriment of services; they overlook the materials and energy efficiency; and they do not include the social dimension of sustainability, in line with a conceptualization of circular economy that focuses on ecological renewal and reduction of finite resource use. The KATCH-e CE Designer online tool is the result achieved within the project and aims to translate into the design practice for the circular economy the design strategies and their related criteria developed and defined through extensive research developed in the four partner countries, Portugal, Spain, Austria and Denmark. Through this resource, designers and product developers have access to relevant information and guidelines that enable a holistic and efficient approach that is expected to contribute to the development of new products, new services, and new production and consumption habits towards a more sustainable and circular society.

The tool which is currently in the process of being tested and adapted according to the feedback will have the final version available online and free of charge in December 2019. The tools have a generalist approach, however, in the future, if necessary, they can be adapted to specific industries, products and / or sectors.

Acknowledgements and disclaimer

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A Tool for Charting Circular Consumption Journeys

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Abstract

Circular economy proponents often argue that products should be designed to last long, be fit for circular (re-) production flows, and be offered through circular services. While this is essential for bringing about a transition to a circular economy, changes in consumption are equally important. Transitioning from linear consumption processes (i.e. buying new products, using, and disposing of them as trash) to circular consumption processes (i.e. obtaining pre-used products, using, and passing them on to others) can however be challenging for people. Renting, borrowing, trading and other circular paths of consumption commonly require more time, effort and planning than linear paths of consumption. In order to make it more preferable for people to circulate products from consumer to consumer, products and services should be designed to make circularity convenient and desirable in everyday life. Such design processes require an in-depth understanding of people's consumption processes. Yet, the available support to explore what circular consumption processes entail for people in everyday life is insufficient. Therefore, this paper introduces a tool for charting circular consumption journeys, which can support the development of products and services fit for circularity. This tool was developed during 2016-2019 in an iterative process in which the tool was tested by industry representatives and design students. In parallel with these activities, a team of researchers continuously developed and refined the tool based on gained insights. The tool aids designers and other agents to chart people's consumption processes step-by-step, with a focus on people's activities, actions, decisions and experiences. By charting circular consumption journeys, insight can be gained regarding critical hinders that may keep people from engaging in circular consumption. Moreover, it will unveil consumption-related challenges that should be addressed when designing circular products and services. Overall, the tool can aid organisations to both increase their understanding of circular consumption processes and to explore opportunities to develop products and services for a circular economy.

Keywords: Circular Consumption, Design tool, Circular Design, Consumption processes, Circular Economy

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1. Introduction

Literature on design and the circular economy commonly highlights opportunities to design products so that they last long, are fit for circular (re-) production flows, and can be offered through circular services that can increase product utilisation (see e.g. Bakker et al., 2014; Bocken et al., 2016). The prevalent narrative regarding design opportunities for circularity is framed from a production and business model point of view, which emphasizes opportunities for primarily changing how products are produced and offered (Selvefors et al., 2018). Although innovations in production and business are essential for bringing about a transition to a circular economy, changes in consumption are equally important (EEA, 2015; Kirchherr et al., 2017; de los Rios and Charnley, 2016). Hence, there is a need to think beyond the current narrative of exploring opportunities for circularity solely from a production and business model point of view, and also address opportunities from a consumption point of view.

Design opportunities can be explored from a consumer point by taking people's consumption processes as a point of departure (Selvefors et al., 2019). A general consumption process can be considered to cover three main phases: obtainment, use, and riddance (see e.g. Antonides and Van Raaij, 1998; Jacoby et al., 1977; Lehtonen, 2003; Lucas, 2002). Throughout such a process, people have many options to engage in alternative modes of consumption, i.e. possible paths of consumption (Selvefors et al., 2019). As illustrated in grey in Figure 1, people can choose to obtain new products and dispose of them as trash in a linear fashion, but they can also choose to obtain and rid themselves of products through circular paths of consumption. They can pass on products in such a way that the products' parts or material can be recovered, and they can also salvage parts or materials as an alternative to buying new products. More importantly however, as illustrated in colour, they can obtain pre-used products and pass products on in such a way that they can be reused by someone else. Each path of consumption necessitates different strings of activities, decisions and experiences that typically influence which paths that are possible to carry out and/or are desirable for people to consider. Adopting a particular consumption path may afford people opportunities to engage in desirable activities, or may deny them such opportunities. People can also be forced to engage in undesirable activities, as well as to be relieved of them (cf. Hiort af Ornäs and Rexfelt, 2006)

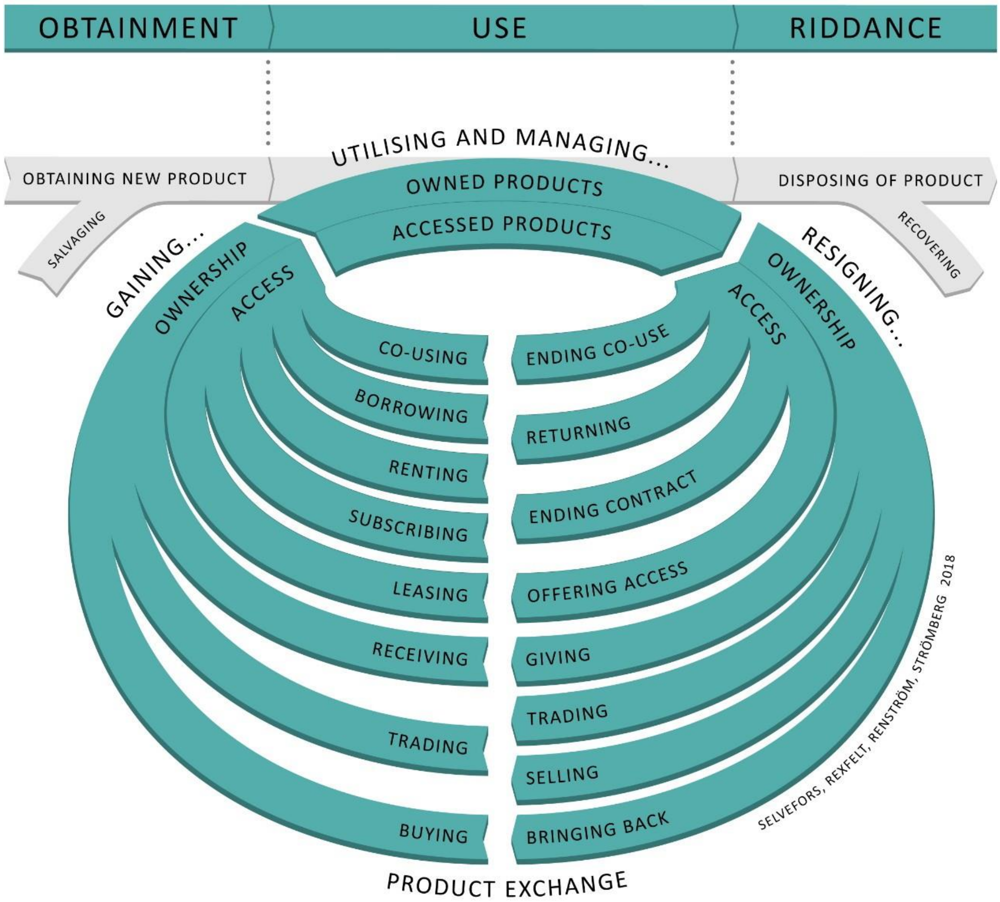

***Figure 1**. Product circularity framed from a consumer point of view, highlighting circular paths of consumption in relation to a linear consumption process. (Adapted from Selvefors et al., 2019).*

People have many possibilities to shift from linear paths of consumption (i.e. buying new products, using, and disposing of them as trash) to circular paths of consumption (i.e. obtaining pre-used products, using, and passing them on to others), but these alternatives are commonly not preferred as they often involve undesirable activities, difficult decisions, and negative experiences. For instance, circular paths of consumption, such as renting, borrowing, or trading products so that they are circulated from use to use commonly require more time, effort and planning than linear paths of consumption. To reduce the risk of having to engage in undesirable activities, people might avoid certain consumption paths (e.g. selling used products on the second-hand market) and choose a more convenient option (e.g. disposing of it as trash or storing it in the garage). If linear instead of circular consumption processes are preferred, products will not be circulated and the transition to a circular economy will not gain momentum.

In order for circular consumption to become preferable and desirable for people in everyday life, products and services must be designed in a way so that they are fit for circular consumption processes. When exploring such design opportunities, it is key to have an in-depth understanding of what circular consumption, compared to linear consumption, entails for people with regard to using, managing, and circulating products. Yet, the available

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support for designers and other agents to explore what circular consumption processes entail for people and design is insufficient. Available circular design tools, such as The Circular Design guide (IDEO and Ellen MacArthur Foundation, 2018), Business as Unusual (Mackatsoris et al., 2017), and the Circular Pathfinder (van Dam et al., 2017), can aid exploration of different types of design opportunities, but they primarily focus on design opportunities related to production processes and/or business models. They do take (some) aspects related to consumption into consideration, such as circularity-related behaviours and factors influencing acceptance of circular offers (Camacho-Otero et al., 2019 forthcoming), but do not sufficiently address the changes in activities, decisions and experiences that circular consumption compared to linear consumption often entails for people. As a consequence, important design opportunities to support circular consumption, such as designing products that make it easy for people to inspect, value, or disassemble a product, are often overlooked (Selvefors et al., 2019).

The aim of this paper is to introduce a new circular design tool that has been developed to especially support designers and other agents to explore people's consumption processes and identify relevant design challenges, which can support the development of products and services fit for circular consumption. Following a brief method overview, the tool will be presented along with two design cases to exemplify its use. Implications for design practice will be discussed and the tool is compared with other available tools.

2. Methods

The tool introduced in this paper is one of the results of an explorative and iterative process that began in 2013. The process was initiated with an explorative workshop in which seven researchers in the fields of user-centred design and sustainable design explored how product circularity could be framed with the user taking centre stage. A new user-centred perspective on product circularity, the Use2Use-perspective, was then developed during the following years. For a detailed description see (Selvefors et al., 2018; Selvefors et al., 2019). In 2016, the work to embody this perspective into a design tool was initiated. It was developed and evaluated through five main activities, some of which overlapped each other.

First, workshops were conducted during 2016 and 2017 with designers, product developers and product managers from six companies (in total four workshops, each with 6-8 company representatives) to verify the need for the tool and to identify the requirements on it. The workshops were arranged in collaboration with the Swedish companies Transformator Design and Hultafors Group. The participants were asked to explore circular consumption journeys related to their product and service offers aided by early versions of the tool. The generated ideas and the participants' experiences of using the tools were discussed afterwards, both by the participants and the workshop organisers, and also analysed by the research team.

Second, workshops were held to further improve the tool, according to the results of the initial tests with companies. The focus was to refine the tool into something that could be used to analyse circular consumption even more in depth, i.e. how circular consumption influences people's everyday lives in terms of activities they engage in and the consequences these may have. Three workshops were conducted (each with 3-5 participating researchers) to map out activities, decisions and practicalities in relation to different paths of consumption, e.g. renting, borrowing, and buying second hand.

Third, refined versions of the tool were used as a foundation for workshops with design students in courses on Sustainable Design at Chalmers University of Technology (altogether on six occasions during 2017-2019, each with circa 30 students). The tasks were to gain an understanding of what circular consumption entail for people and come up with innovative ideas to make circular consumption preferable. The generated ideas and the tool's potential to support idea generation were discussed afterwards with the students.

Fourth, refined versions of the tool were also tested by design students in their master thesis projects (in total by 9 students in five teams) to chart consumption journeys relevant for their projects in order to identify design opportunities. The thesis projects concerned the design of a mobile application for sharing (Chalandon and Lindborg, 2019), a digital platform for sharing assets within the culture sector (Lindgren and Trens, 2019), an autonomous delivery droid for collaborative consumption (Janebäck and Kristiansson, 2019), a tent for a rental service (Hagman and Wendt, 2018), and a sofa for a furniture subscription service (Rosman, 2018). The experiences of the thesis students were monitored throughout their projects and all students were interviewed retrospectively to gain insight into their use of the tool and the challenges and implications they had experienced.

Fifth, an empirical study was conducted to gain deep insight into the practicalities of circular consumption processes. The study was carried out together with an upper secondary school in Sweden and 73 pupils took part in the study. Each pupil was challenged to try out two different circular consumption paths during a week. They could, for instance, sell or give away unused items that might be useful for someone else, or they could borrow or buy items they needed from someone else. The pupils documented their activities and experiences in diaries and reflective reports. The purpose of the study was to validate that all activities, decisions and experiences that are commonly part of people's consumption processes can be addressed with the tool.

Through these five activities, insights regarding the tool's potential value and usability were gained from different perspectives and opportunities to improve the tool were identified. The tool was adjusted accordingly and revised into the format presented in this paper.

3. Introducing the Circular journeys exploration tool

The main purpose of the developed tool is to support designers and other agents to identify opportunities to design products and services for circular consumption, by increasing their understanding of how circular consumption processes are carried out and how people experience such processes. As shown in figure 2, the Circular journeys

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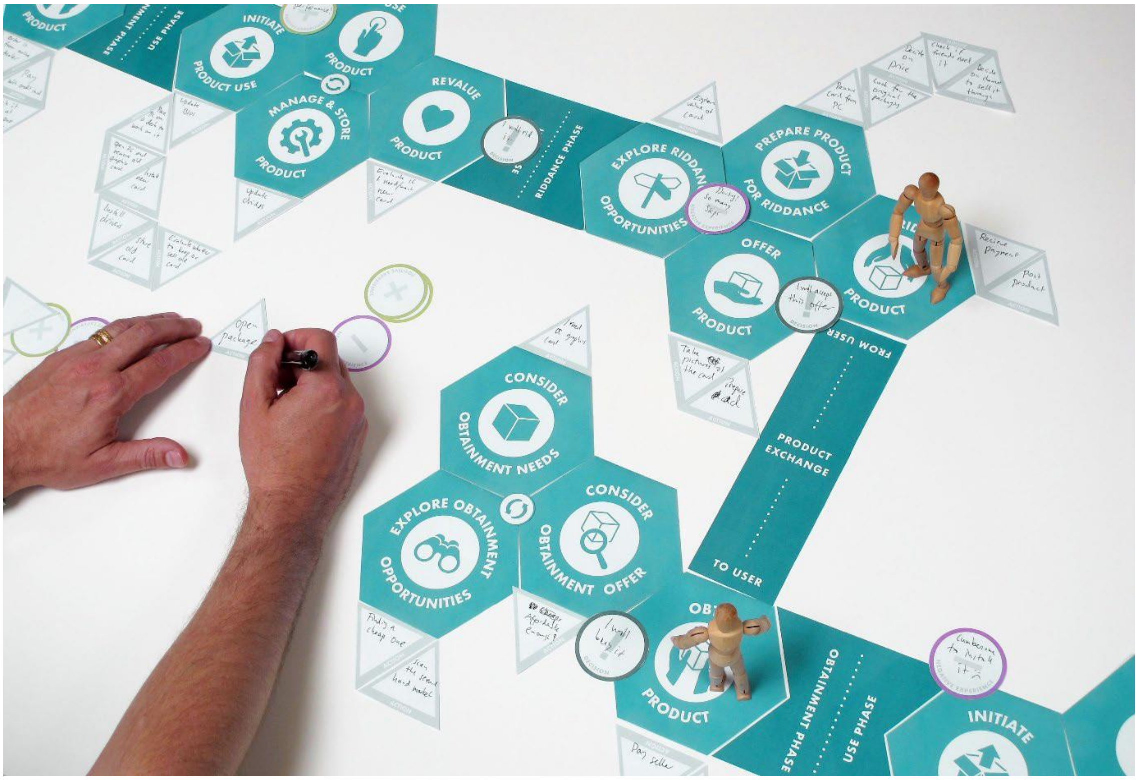

Figure 2*. The Circular journeys exploration tool.*

exploration tool provides a pack of different pieces that facilitates the charting of people's consumption processes. By charting such journeys, insight can be gained into people's activities as well as decisions and positive and negative experiences, which will highlight important design challenges.

Charting consumption processes

The pieces provided can be used to step-by-step map people's activities, actions, decisions and experiences. The most central pieces in the tool are the pre-defined hexagonal activity-pieces, which constitute the backbone of every mapped consumption journey. These pieces are specifically designed to cover activities related to all three phases of a consumption process: obtainment, use and riddance. In total, there are twelve such pieces that describe central consumption activities, such as "Explore obtainment opportunities", "Initiate product use" and "Prepare product for riddance". Other key pieces are the action-pieces, which are used to detail how the main activities are carried out, and pieces to highlight important decisions and experiences that are typically perceived negative or positive by people.

Before starting to chart journeys using the tool it is important to decide what to chart. Doing so involves three main decisions: deciding on the particular path of consumption that is to be explored, deciding on what product that is used and circulated through the process, and deciding on who (i.e. a consumer or a category of consumers) that takes part in the process and carries out the activities. As shown in figure 3, the process to chart consumption processes involves three main steps. Figure 3 illustrates these steps for a journey that describes how a typical consumer buys and sells furniture on the second-hand market.

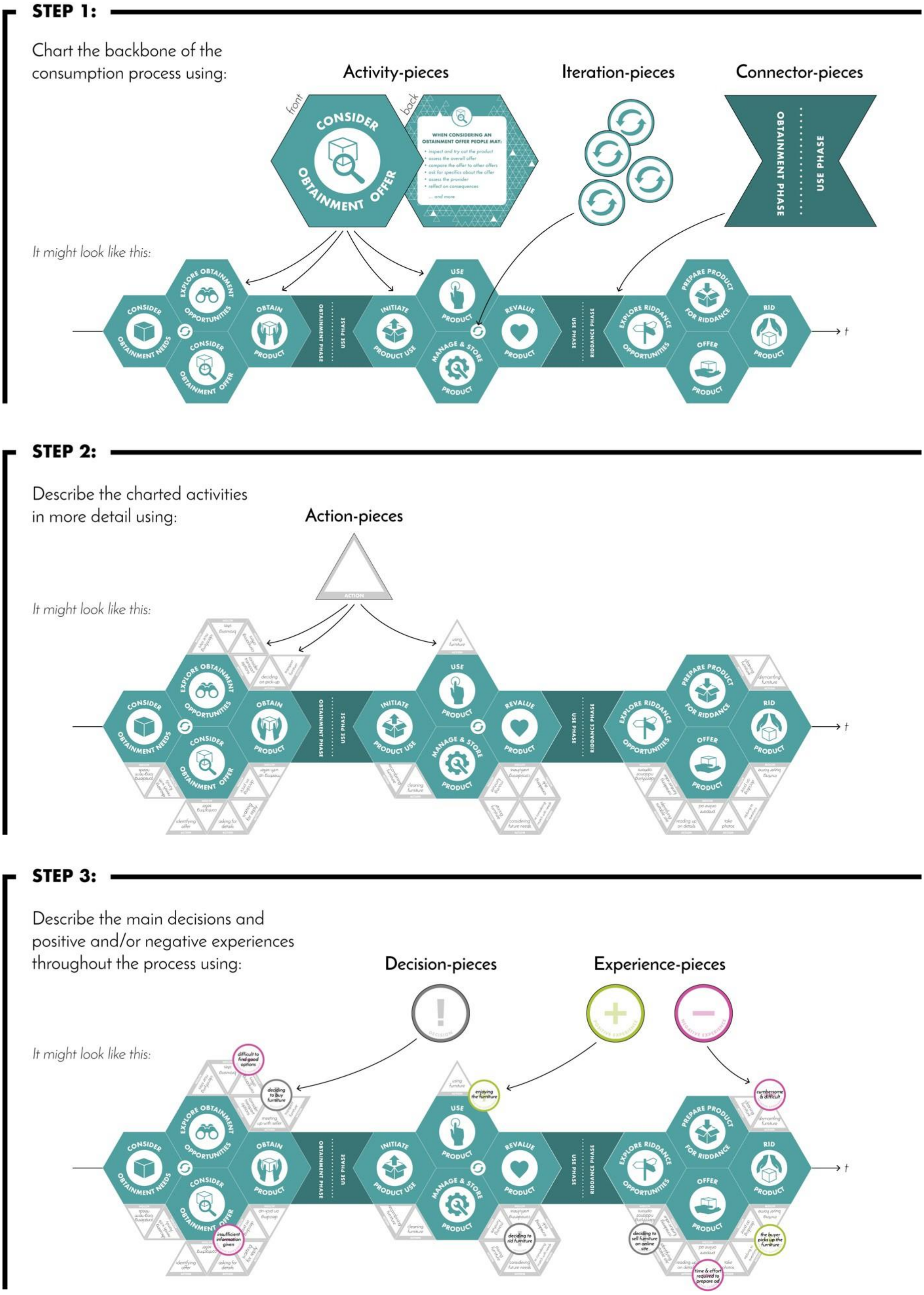

***Figure 3**. How to chart consumption journeys with the Circular journeys exploration tool.*

During Step 1, the backbone of the process is charted using the hexagonal activity-pieces, and if needed iteration- pieces and connector pieces, and laid out on a flat surface such as a table. The backside of the activity-pieces provides examples of what the different main activities may entail in terms of more specific actions, to facilitate the choice and charting of the pieces. The activity-pieces can be grouped into the three main phases

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of consumption, i.e. obtainment, use, and riddance, using the connector-pieces to emphasise the three phases. The pieces are charted with an imagined time-line to describe the consumption process over time. Activities that are carried out in parallel can be placed above/below each other (see placement of e.g. "Explore obtainment opportunities" and "Consider obtainment offer" in figure 3, Step1). In addition to activities carried out in parallel, people may sometimes also iterate between activities. For instance, people may go from using a product, storing it temporarily, revaluing it, using it again, storing it for a longer period, until finally deciding to pass it on after yet another revaluing activity. Such iterations can be indicated using the iteration-pieces (see placement of e.g. "Use product", "Manage & store product" and "Revalue product" in figure 3, Step1).

Once the backbone of the process has been charted, it is time to in more depth explore what people do throughout the process. Step 2 thus involves describing specific actions that people carry out as part of their main consumption activities. By thinking through each step of the process, actions that are important to understand and hence important to highlight can be identified. For instance, when offering furniture on the second-hand market, one may need to identify a suitable sales channel, read up on terms and conditions, identify the furniture's brand and model so that this information can be provided, prepare an ad and take photos, communicate with potential buyers, and more. Actions relevant to pinpoint are actions that in different ways are significant to people and their consumption processes. For example, actions that require a lot of effort or time, are difficult, boring or inconvenient, or bring about particular experiences are important to identify. The examples on the backside of the activity-pieces can be used as inspiration. Once identified, the actions can be described using the action-pieces and placed next to the activity-pieces, see figure 3.

After all relevant actions have been described, people's main decisions and experiences can be added during Step
3. As illustrated in figure 3, decisions-pieces and experience-pieces are used to emphasise the most important decisions and experiences throughout the journey. Two types of experience-pieces are available, which can be used to describe positive and negative experiences respectively. The pieces can be placed on one or several of the action-pieces to in more detail describe the consumption process.

By charting consumption processes according to the three steps outlined above, insights will be gained into important design challenges that can be documented and addressed in subsequent design processes.

Charting opportunities

The tool can be used to chart consumption processes that have already been thoroughly researched through user studies but this is, however, not a prerequisite for using the tool. Less explored journeys can also be charted, based on for instance one's own experience or assumptions. In addition, the tool can be used to mediate user studies to gain novel insights from consumers. Hence, the use of the tool and potential outcomes may vary from case to case. If charting a journey based on previously conducted in-depth user studies or as part of conducting new user studies, one can expect to end up with a rather detailed and realistic description of the journey. This may be advantageous in many cases as it can unveil more design challenges compared to less detailed journeys.

Nevertheless, sometimes a less detailed journey is enough to identify the most critical design challenges to address.

As previously described, journeys can be charted for different paths of consumption, different products, and different consumers. The journey illustrated in figure 3 describes the charting of one particular journey, i.e. how a typical consumer buys and sells pre-used furniture. Figure 4 provides additional examples of journeys that describe different paths of consumption and focus on other products. As illustrated by the figures, the tool can be used to chart consumption processes with different character, that include different activities and actions and that involve different types of decisions and experiences at different stages during the process. As shown by the first journey in figure 4, the tool can be used to chart a journey for a specific consumer, or a category of consumers, throughout the entire consumption process, i.e. the three phases obtainment, use, and riddance. The tool can however also be used to chart a particularly interesting segment of a consumption process or the link between two consumers' consumption processes. For instance, the tool can be used to chart a product exchange process in which a product is transferred from one consumer to another, as illustrated by the other two journeys in figure 4. For such journeys, two consumers, or categories of consumers, needs to be considered. Moreover, their relation is essential to define as the process may look very different depending on if they are family, friends, or strangers.

Furthermore, by charting two or more journeys these can be compared to gain insight into why people may prefer one particular path of consumption over another. Depending on the case at hand, there are several types of journeys that may be relevant to compare. First, it can be interesting to chart several journeys in which a consumer follows the same path of consumption, e.g. selling a product, but interacts with or makes use of different services or exchange agents during the process, e.g. selling a product on eBay or Facebook Marketplace. By defining what services or exchange agents that are involved in the processes, it becomes easier to describe the processes in more detail and to identify their differences. This may in turn provide valuable insight into relevant design challenges. Another comparison that can be relevant is to compare journeys that describe different paths of consumption, for example, comparing a linear consumption journey with a journey for a circular path of consumption such as renting, subscribing or borrowing. By doing such a comparison one can better understand why people may consider linear consumption more preferable than circular alternatives, which may aid the identification of design opportunities (for an example, see Rosman, 2018). Yet another relevant comparison to make is to compare the journeys of a current consumption process and a potential future process, which involves a new product, services or exchange agent. This type of comparison allows for a before/after analysis and makes it possible to 'prototype' potential future journeys in relation to a particular offer (for an example, see Chalandon and Lindborg, 2019).

Accessing the tool

The tool for charting circular journeys introduced in this paper is part of the Use2Use design toolkit, which includes five mind-expanding packs designed to boost product circularity by aiding the development of products and services fit for circular consumption processes. Together, the five tools address elicitation of user needs, specification of design challenges, concept generation and evaluation in early phases of a user-centred design process. The toolkit is freely available at www.use2use.se (from 1 September 2019).

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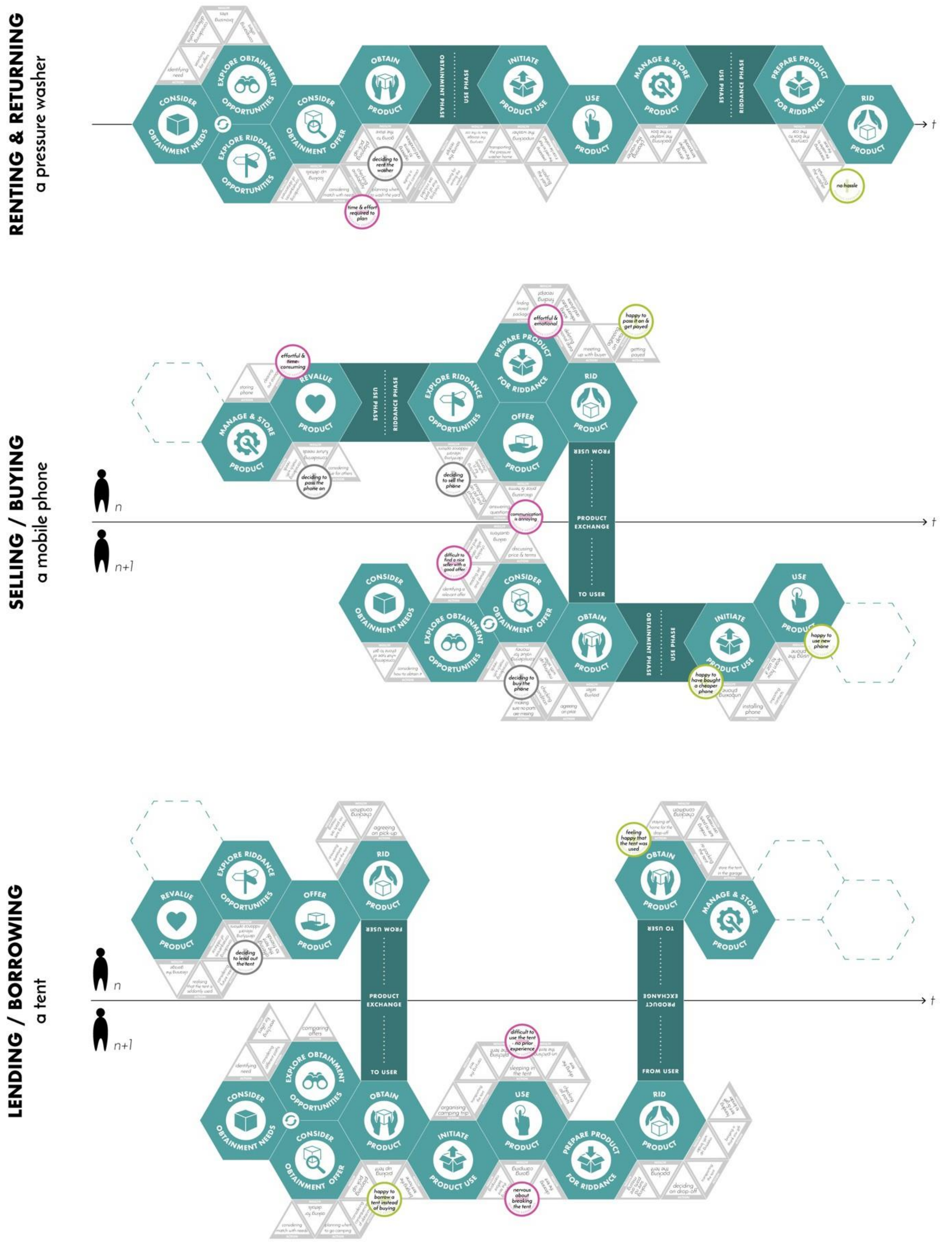

Figure 4. *The tool can be used to chart consumption journeys of various character*

4. The tool in use: two design cases

This section describes two examples of how the tool has been applied in design cases. The examples illustrate different contexts in which the tools can be used, ways in which it can be applied in practice, and what type of design challenges and opportunities that can be identified by using the tool.

Case 1: The design of a mobile application for sharing

In 2019, a master thesis project (Chalandon and Lindborg, 2019) was carried out by two design students at Chalmers University of Gothenburg aiming to integrate a feature into an inventory management app that would enable the people to borrow products from one another. The initiator of the project was the start-up company Futuresaurus AB, who had developed the inventory management mobile application Sortapp. The company was interested in exploring the sharing potential that an inventory app entails, i.e. digital inventories can be used to make it easier for people to see what products others have and to make requests to borrow them.

The Circular journeys exploration tool was applied by the two students during a workshop in the project, see figure 5. The workshop was facilitated by two researchers (the developers of the tool and authors of this paper). Before the workshop the students had carried out user studies through surveys and interviews, and they had a fair understanding of the apps' targeted users and their requirements. The students decided to chart two consumptions journeys: (1) how products are lent/borrowed today, and (2) how product might be lent/borrowed in the future using the app. In the workshop, they choose to address a ski jacket, since such a product is typically used periodically and is suitable to lend to someone. They also choose to chart the journey for a pair of neighbours, since such a relation might make the consumption process more challenging than if the consumers had been close friends.

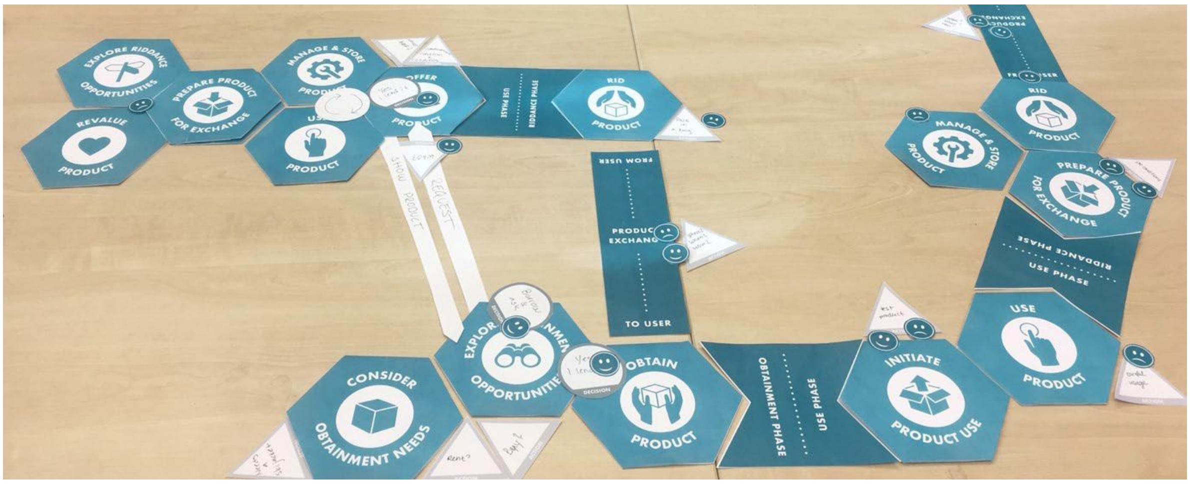

***Figure 5**. A previous version of the tool being used to chart the process of a consumer borrowing a ski jacket from a neighbour.*

By charting the first journey (how products are lent/borrowed today), a number of valuable insights were gained. Most important of these were the identification of hinders that today often stop lending/borrowing from happening, for example:

- People are unaware of what products other people have, particularly people one isn't friends with.
- If people happen to know what products other people have, they do not know if they are willing to lend them …and they find it a bit embarrassing to ask.
- If people borrow something one might be afraid to use it as if it were one's own …and if problems occur (e.g. the product breaks down, gets lost, or that it is not handed back in time) things might get very

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complicated, since you generally have rather loose terms for how these situations are to be handled.

When charting the second journey (how product might be lent/borrowed in a future using the app), it became apparent how large potential the app had to alleviate these hinders. This helped the students to pinpoint what to focus on when designing the new functions of the app, for example:

- When a user of the app adds a product to their digital inventory, they need to be able to define whether they are willing to lend it to someone …and to whom. Is it just to friends, or anybody in general?
- The users also need to be able to state the terms for this, e.g. for how long the product can be borrowed, and how it should be returned etc. 'Standard terms' that can be assigned to the products can make this process more efficient.
- Users who are looking for a product to borrow need an effective search function and a non-intrusive way requesting the product.

In retrospect, the students stated that the Circular journeys exploration tool was vital for their project. In particular, using the tool helped them to put the finger on exactly how the app could support people's processes of lending/borrowing products, and what features to include in the app.

Case 2: The design of a digital platform for sharing products within the culture sector

In another master thesis project carried out at Chalmers University of Gothenburg (Lindgren and Trens, 2019), two students developed a digital platform for product sharing within the culture sector. The initiator of the project was the environmental organisation Returkultur, who are exploring the possibilities to establish a pool of equipment, such as light/sound equipment and music instruments, that will available to actors in the culture sector in the west of Sweden. Currently, cultural institutions like the Gothenburg Opera throw away a lot of equipment that through Returkultur's pool could become valuable to smaller cultural organisations or individuals.

The Circular journeys exploration tool was applied during a workshop in the project. The workshop, which was facilitated by the students, engaged nine potential users all active in the culture sector (DJs, artists, actors etc.). Before the workshop the students had carried out user studies and had a fair understanding of the widespread informal sharing scene among actors in the culture sector. In preparation for the workshops, the students used the tool to chart a typical sharing journey based on their collected data and their understanding of the sharing processes in the culture sector. This journey was introduced to the participants in the workshop, and they were asked to modify it to make it more correspondent with their own experiences of sharing. All participants however thought it was a good representation of the sharing process and opted not to adjust it. In the next part of the workshop, each participant was given a piece of paper on which they, separately and in silence, wrote down their typical actions and considerations for each stage of the sharing process, see figure 6. To help and guide them they had questions for each phase proposing actions, considerations and problematic areas, such as "How does the need for a product arise?", and "What aspects determine what you do with the product after use?". After this exercise the participants read their thoughts out loud and discussed them in the group. This discussion was recorded and the students took additional notes.

Figure 6*. A previous version of the tool being used in a workshop with users. (Lindgren and Trens, 2019)*

Similar to Case 1, this case used the Circular journeys exploration tool to chart the users' circular consumption processes based on insights from user studies. However, the students in this project also used their charted journey to gain additional insights from users. According to the students this was very valuable, and their approach of letting the users reflect on each hexagonal activity piece was an effective way to carry it out. Through this approach, the students could elicit rather detailed user requirements related to each step of the consumption process. As an example, requirements on what info the users' need during the activity "Consider obtainment offer" included: Product availability, Picture of the product, Product weight, Product dimensions, Product compatibility, Product manual, Product specifications (electricity type etc.), Product accessories (needed cables etc.), Product complexity, Condition of specific product, Pick-up/drop-off location, Accessibility at pick-up/drop-off location, Pick-up/drop-off process, and Service hours at pick-up/drop-off location. According to the students, to gain insight into such user requirements for every step of the users' consumption processes was extremely helpful when designing a digital platform to support sharing.

5. Discussion

The contribution will be discussed in regard to the tool's implications for design practice. In addition, the tool is compared to other available tools and plans for future work are described.

Implications for design practice

The tool has been developed based on a user-centred design philosophy, i.e. that the more a designer knows about a user's situation or process, the better equipped she/he is to develop solutions that meet user needs in a way that is appreciated and preferable by users. The tool is hence designed to support designers and other agents to

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explore people's consumption processes in depth so that they can identify design opportunities and develop attractive circular offers. Although this is the tool's primary purpose, it can also be used for a number of other purposes. As already highlighted, the tool can be used to collect new insights during user studies, to compile previously collected insights, to prototype new consumption processes or offers, and to compare and evaluate journeys for different offers. Hence, the tool can prove beneficial for a number of different design activities in the early stages of a design process. In particular, its value lies in its potential to aid designers and others to embrace a consumer perspective to better understand circularity and explore opportunities to support circular consumption. As it takes people's consumption processes as a point of departure and supports the identification of design challenges from a consumer perspective, it presents a unique circular design tool that can complement the already existing tools available to designers.

Comparison with other available tools

If one considers design tools which are not specifically adapted for circular design, there is a range of other tools and methods available which aim to provide insights into what people do and to increase the understanding of user/customer processes. These include methods often applied in the field of Human-Machine Interaction and Human-Computer Interaction, such as Cognitive Walkthrough (Wharton et al., 1994), Predictive Human Error Analysis (Baber and Stanton, 1996), and Usability testing (Nielsen, 1993). These methods are however less useful to gain insights into consumption processes, since they focus on the specifics of interaction. Another method is Critical Incident technique (Flanagan, 1954), which is a task analysis method that is used to pinpoint the reasons for human error in tasks such as piloting planes and performing surgery. Yet another method that incorporates people's courses of actions is Service blueprinting (Shostack, 1994), which is used to visualise the relationships between different service components. While it does include the customer as one of those components, it also has an equal focus on the backstage processes needed to deliver the service, making it overly complex if one is only interested in the users'/customers' processes.

One popular method among designers, which seems to be the one that is most comparable with the tool presented in this paper, is Customer journey mapping (see e.g. Stickdorn and Schneider, 2010; Trischler and Zehrer, 2012). It is commonly used to visualise the process that a person goes through in relation to a specific service, in order to increase the understanding of customer needs and pain points. It encompasses what the customer generally does in this process and how she/he generally experiences it, often from the perspective of one or more personas and rarely from the perspective of a single customer.

The journey is typically divided into different phases or stages, often covering the customer experiences related to different touchpoints before, during and after interacting with the service. Customer journey mapping has similarities with the tool presented in this paper. Both tools can be used to map out existing journeys, and to prototype new journeys (although customer journey maps predominantly are used to map existing ones (Følstad and Kvale, 2018)). They can also both be used to chart journeys based on thorough empirical data from user studies, but also more hypothetical ones based on the existing understanding among the agents who are using the tool. There are however also important differences between customer journey maps and the tool presented here, and three significant ones will be discussed.

First, the Circular journeys exploration tool can be used to map consumption journeys that are not tied to a specific service or company. The point of departure for the circular journeys are the paths of consumption, such as renting, borrowing and buying second hand, and these journeys can include interactions with a variety of companies. This can provide a richer description of the consumer's everyday consumption processes, which rarely revolves around an isolated business or service. There are also paths of consumption that are carried out without the involvement of companies at all, such as borrowing something from a neighbour, which can be charted using the tool. In addition, the more open-ended approach in the introduced tool may help designers to identify more radical design opportunities, while Customer journey mapping often focus on refining existing services and working out its associated kinks. The tool presented in this paper however requires that the consumption journeys to be charted includes the flow of one or more products. This means that the tool cannot be used to chart journeys where products are not handled by consumers, such as for instance the process of hiring a painter (which can be explored using customer journey mapping). This is a prerequisite for our tool, since the overall purpose of using it is to reduce linear consumption by making circular alternatives more attractive.

Second, the introduced tool provides a set of pre-defined pieces to chart the journeys. This enables a top-down approach to charting, starting by laying out the hexagonal activity pieces to form the backbone of the journey and then fleshing it out. Customer journey maps starts without any predefined pieces (even though a pre-defined canvas to help sketch the journey might be applied), meaning that the overall structure of the journey often needs to be defined during the exercise. There are a number of advantages of using pre-defined pieces. It is easier to use, making it possible to use the tool without expert facilitators present. It is also faster, allowing for alternative journeys to be rapidly charted and compared. Additionally, the pieces can also function as a check-list, since the people using the tool will consider all pieces during the charting process. However, the major potential drawback of using pre-defined pieces is the reduced flexibility this entail. The pieces might force the charting of journeys that deviates from people's actual consumption journeys. To evaluate if this is a valid concern for the presented tool, the 146 description of circular consumption processes collected from the 73 Swedish upper secondary school pupils were analysed with this risk in mind. All activities included in the descriptions could be represented by the tool's hexagonal activity-pieces. Among the master students who applied the tool in their design processes this was not a problem either, although the students in Case 1 opted to tweak the tool slightly by adding custom pieces that visualized the communication between different consumers more clearly.

A third significant difference between the introduced tool and customer journey mapping is that while customer journey maps generally have both an analytic and communicative purpose, i.e. their utility lies both in the process of creating them, and in the process of communicating their end results with others. Customer journey maps are, in their final form, often of a relatively high fidelity, since that polish will enable more effective communication. When charting consumption processes with the presented tool, the purpose is predominantly analytic. The main takeaway is the insights you get during the charting process and, if you use the tool to prototype new processes, the descriptions you get of these processes. While these insights and processes may be documented when the charting is done, it may not be optimal to communicate it to someone who has not been part of the charting process (as an example, when a reader of this paper looks at the figures with charted journeys, it is probably difficult to draw the same conclusions as the persons who were part of charting them could). There is however nothing that prevents someone who have used the tool to afterwards apply a more communicative method to make the results easier to understand. One such method that is suitable to communicate consumption processes is Storyboarding (see e.g. Babich, 2017), which has the goal of producing sequences of illustrations arranged to illustrate a course of events. Another option could be to illustrate the findings though infographics

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(see e.g. Smiciklas, 2012), which was a strategy that the students in Case 2 applied effectively.

While customer journey mapping often is used as a design tool, a different customer journey approach has evolved within the field of marketing (Følstad and Kvale, 2018). In this field, the customer journeys focus on the process of purchasing a product or service, i.e. certain aspects of the obtainment phase, and the customers' decisions during this process. This approach is of limited use when designing for circularity since it does not encompass the entire consumption process. Addressing the full process, i.e. the three phases obtainment, use and riddance, is crucial since certain combinations for obtainment and riddance paths are prerequisites for product circularity. Nevertheless, exploring consumption processes from a business and marketing perspective can provide complementary insights valuable for design, since marketing has a big influence on people's consumption-related decisions.

In summary, the presented Circular journeys exploration tool has some things in common with already available design tools, but it also has important differences. The tool is designed to be easier, more effective and more efficient to use for gaining insight into circular consumption processes. These advantages have their roots in that the tool has been custom made to be applied in this specific setting.

Future work

Although the tool already provides a new way for designers and other agents to gain insight into people's consumption processes and related design challenges, it is in need of additional testing and possibly also further development. Supplementary testing of the tool will be conducted to explore the tool's usefulness for studying people's consumption processes and gaining insight into challenges that are relevant to address when aiming to design products and services fit for circular consumption. Such evaluative studies will also address the tool's user friendliness, fit with companies' current design processes and other tools in use, and its potential to contribute to new innovative designs fit for circular consumption. Activities to test the tool will be carried out with representatives from industry in upcoming research projects but also with design students.

6. Conclusions

This paper introduces a tool for charting circular consumption journeys, which should be seen as complementary to previously suggested tools for circular design. In contrast to other tools, the introduced tool provides support to explore circular design opportunities from a consumer perspective, with a specific focus on people's consumption processes and their related activities, decisions and experiences.

The presented tool helps designers and other agents to chart people's consumption journeys step-by-step. Different types of consumption journeys can be mapped by linking consumer activities and actions identified to be of special importance for circular journeys compared to linear journeys. By doing so, insight can be gained regarding critical hinders that may keep people from engaging in circular consumption. Such insight is vital when identifying new design opportunities for developing circular products and services that have the potential to make circular consumption preferable for people. The tool can be used to chart existing consumption journeys based on empirical data, to mediate user studies, and to prototype future journeys. Overall, the tool can aid organisations to both increase their understanding of circular consumption processes and to explore opportunities to develop products and services for a circular economy.

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KATCH_e: Training materials and tools for circular economy in practice

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Abstract

KATCH_e is a knowledge alliance between research centres, universities and companies to build competences in the field of product-service development for the circular economy and sustainability. This ERASMUS + funded project comprises eleven partners from Portugal, Spain, Austria and Denmark engaged in advancing knowledge and experiences in the transition from a linear economy to a circular and more sustainable economy with a special focus in the construction and furniture sectors. There is nowadays a myriad of training courses, books, manuals, standards, reports, tools and all sorts of resources related to circular economy. Therefore, one of the main challenges for the consortium was to bring novelty to what is already available and this was achieved through (i) the systemizing of existing, disperse knowledge, keeping in mind the applicability in Higher Education study programmes and in companies, together with the target sectors; and (ii) the development of new contents and tools where gaps existed. The approach followed is framed by the understanding of circular economy in KATCH_e: “Circular economy is a system that is restorative and regenerative by intention and design, which supports ecosystem functioning and human well-being with the aim of accomplishing sustainable development. It replaces the end-of-life concept with closing, slowing and narrowing the resource flows in production, distribution and consumption processes, extracting economical value and usefulness of materials, equipment and goods for the longest possible time, in cycles energized by renewable sources. It is enabled by design, innovation, new business and organizational models and responsible production and consumption”. Following this understanding, eight theoretical modules and seven practical tools have been developed, according to a framework organized in four main areas: (1) Basic knowledge (provided by the “Introduction to the CE” theoretical module and the “KATCH-Up Board game”); (2) The business approach, required for the success of new, more circular and sustainable products or product-service combinations (“Business models” and “Value Chains” modules,

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complemented by the "CE Strategist" and the "CE Value Chains" tools); (3) a third area dedicated to product and product-service system design (with three modules, "Processes and Materials, "Design and development and "Radical innovation and collaborative design processes" and two tools, "CE Designer" and "Circular Economy Journey Map"); and (4) a support area for assessment and communication ("modules Life cycle perspective" and "Communication" in circular economy (supported by two tools: "CE Analyst" and "KATCHing Carbon"). This paper presents the foundations and characteristics of these innovative, multidisciplinary training materials and tools, as well as preliminary experiences in relation to their testing, both in-classroom and in company environments, and with the support of a wide stakeholder`s network.

Keywords: Circular Economy, Circular Design, Tools, Training Materials, Higher Education

KATCH_e: Training materials and tools for circular economy in practice

1. Introduction

The circular economy (CE) represents a fundamental alternative to the linear take-make-consume-dispose economic model that currently predominates. This linear model assumes that natural resources are available, abundant, easy to source and cheap to dispose of, but it is not sustainable, as the world is moving towards, and is in some cases exceeding, planetary boundaries (EEA, 2016). Therefore, we need a fundamental transition into a more sustainable consumption and production system. In a circular model, on the other side, waste and pollution are designed out, products and materials are kept in use and values sustained for as long as possible – and natural systems are regenerated (Ellen MacArthur Foundation, 2012).

The idea of a CE is not new but goes back to the 60s and 70s (Boulding, 1966; Nicholas Georgescu-Roegen, 1975). However, it was not until the beginning of the 90s that the term CE emerged, when introduced by Pearce and Turner in 1990. In 2012, the concept re-emerged as the Ellen MacArthur Foundation published their first of many publications on CE (Ellen MacArthur Foundation, 2012). The CE approach is having a fast development and is receiving increasing attention worldwide to overcome the current production and consumption models based in "linear economy" or "take, make and dispose model" that depletes natural resources and destroys ecosystems.

The concept has spread to the political arena with amongst other the European Commission's Action Plan to a Circular Economy (European Commission, 2015), and a revision of a number of directives such as the waste framework directive and the directive on packaging waste (European Commission, 2008, EUR-Lex, 2018).

Design plays a crucial role in CE and this is not only about recycling, but also about durability, maintenance, repair, sharing, reuse, refurbishment and remanufacturing. Design has the power of enabling or hindering these features. It determines the circularity potential of products, services and systems. Traditionally, designers would focus exclusively on products, but their role is evolving (De Groene Zaak and Ethica, 2015). Given that the design of a product directly influences the way a value chain will be managed, building circular, globally sustainable value chains inevitably signifies a fundamental change in the practice of design. A variety of new capabilities are key competences to design for a sustainable future; these range from a deeper knowledge of material composition to a rich understanding of social behaviour (De los Rios and Charnley, 2017).

Nowadays designers and "developers need to cooperate to co-create and produce utility in which the possible services and performance, safety, collection, recycling, littering and end-of-life possibilities are taken into account, like cascading, refurbishing, reuse or biodegradation" (Kok et al., 2013:22), and replacing products with services. However, the current knowledge base to turn theory into practice is fragmented and studies point to the need of adequate skills and education for CE (EEA, 2016), and that the principles of a CE should become an integral part of education programs.

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This paper presents the European project KATCH_e - Knowledge Alliance on Product-Service Development towards Circular Economy and Sustainability in Higher Education. This is a 3-years EU funded project that will be concluded by the end of 2019 and is part of the ERASMUS+ programme of Knowledge Alliances. The project consortium integrates 11 partners from four EU countries to address the challenge of reinforcing the skills and

competences in the field of product-service development for the CE and sustainability in the construction and furniture sectors through the development of innovative training materials and tools addressing professors, students and professionals in the respective industries.

The project contributes to:

1.1 Build a lasting knowledge alliance between universities, companies and knowledge centres by encouraging multidisciplinary relationships and supporting the exchange of information, experiences and materials amongst the partnership and between different stakeholders through the creation of structures to engage students, professors, researchers, companies and other stakeholders in a systematic and efficient way.
1.2 Build competences in design for the CE and sustainability by the development of training materials that follow a problem-based and multidisciplinary learning approach, connecting designers, engineers and other relevant stakeholders to integrate CE thinking in design and development education and define didactic recommendations for teaching. The resources developed will foster entrepreneurial skills leading to innovative products, services and business models.
1.3 Support and promote the dissemination of circular design and sustainability among higher education centres and companies, demonstrating the practicability of the materials, their benefits and innovation potential.

2 Circular economy within KATCH_ e – conceptualization and definition

Despite its popularity, the understanding of the CE concept is far from consensual, as shown in an analysis of 114 definitions performed by Kirchherr et al. (2017). Therefore, in the KATCH_e project, the consortium developed its own definition of CE, meant to suite the projects' objectives, operational approach and sectors. It has its roots in the definition provided by the Ellen MacArthur Foundation in a report published in 2012, called seminal and "assumed that it has likely impacted the discourse" (Kirchherr et al., 2017: 225) about CE. However, this definition was criticized for not specifying the needs for reducing consumption levels and for not including the social aspects of sustainability.

With these considerations in mind, and in order to frame the development of the KATCH_e training materials and tools, the Ellen MacArthur Foundation (2012) definition was used as the main source of the project's definition, adding the ideas of slowing, closing and narrowing resource flows and social sustainability, as shown in figure 1.

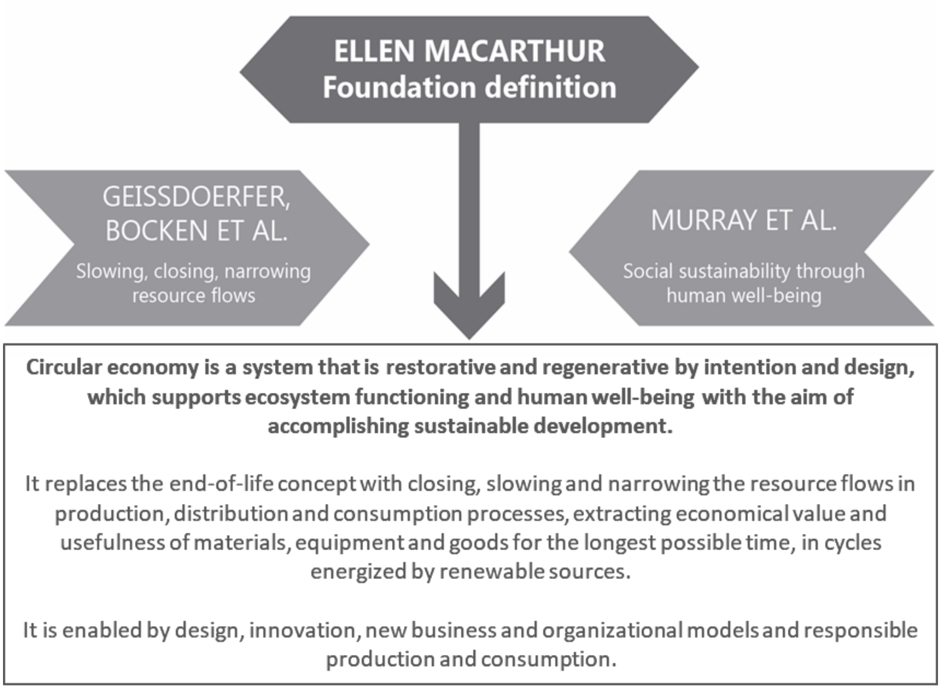

Figure 1. *Development of the KATCH_e definition of CE.*

3 State of the art and trends in training for a CE in the construction and furniture sectors

The transition from a linear to a circular economy is a key challenge for all actors in the society, and universities have a central role. Graduates should be able to rethink and co-develop new solutions for CE from a multidisciplinary approach. This is very much in line with the 21st-century learning skills developed by the World Economic Forum, defining key competences such as: critical thinking and problem solving; creativity; communication; and collaboration (Soffel, 2016).

Studies point to the need for adequate skills and education for the CE (EEA, 2016). Thus, it was important to know which skills are needed and how they are covered by the training already offered by higher education institutions in order to prioritize contents and define the didactic materials and learning approaches that should be developed by the project.

To this end, a research was done to describe the current situation of CE and sustainability in higher education mainly in the partner countries and business related to the construction and furniture sectors from the perspective of multidisciplinary key stakeholders (KATCH_e, 2018).

In order to know the training offer in CE, sustainability and related subjects, a detailed bibliographic review was done on:

3.1 Databases and software;
3.2 Books and guides;
3.3 Related projects;
3.4 Websites and platforms;

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3.5 Standards and ecolabels; and

3.6 Tools.

Moreover, 73 training offers (official masters, postgraduate courses, and independent courses) from the four KATCH_e countries related to design, and the furniture and construction sectors were analysed. The main subjects were grouped into three categories: environment, economics and design (table 1).

Table 1. *Main topics covered by the training offered by universities of the four KATCH_e countries.*

Topics	**Main subjects**
Environment	Circular economy Resource efficiency Resource cascading Reuse, repair, remanufacture, recycle
Economics	Industrial symbiosis Sustainable business model Product-service systems Circular business model Performance economy
Design	Design for sustainability Circular design Cradle-to-cradle design

Figure 2 shows, for training offers in higher education (HE) related to different thematic areas, the percentage in which each topic is present. In trainings explicitly designated as “Circular Economy”, the CE topic is obviously the most frequent subject (29%) followed by circular business models (14%). Regarding courses on waste management, CE, reuse/repair/remanufacture/recycle and others are present in equal parts. In business related training offers, there are contents, in equal parts (10%), about CE, resource efficiency, sustainable business models, circular business models, performance economy, design for sustainability and social innovation. In the training offers on design, the most frequent topic is design for sustainability, but “others” represents 39% what shows that other aspects about CE, out of the topics considered in this research, are mostly considered.

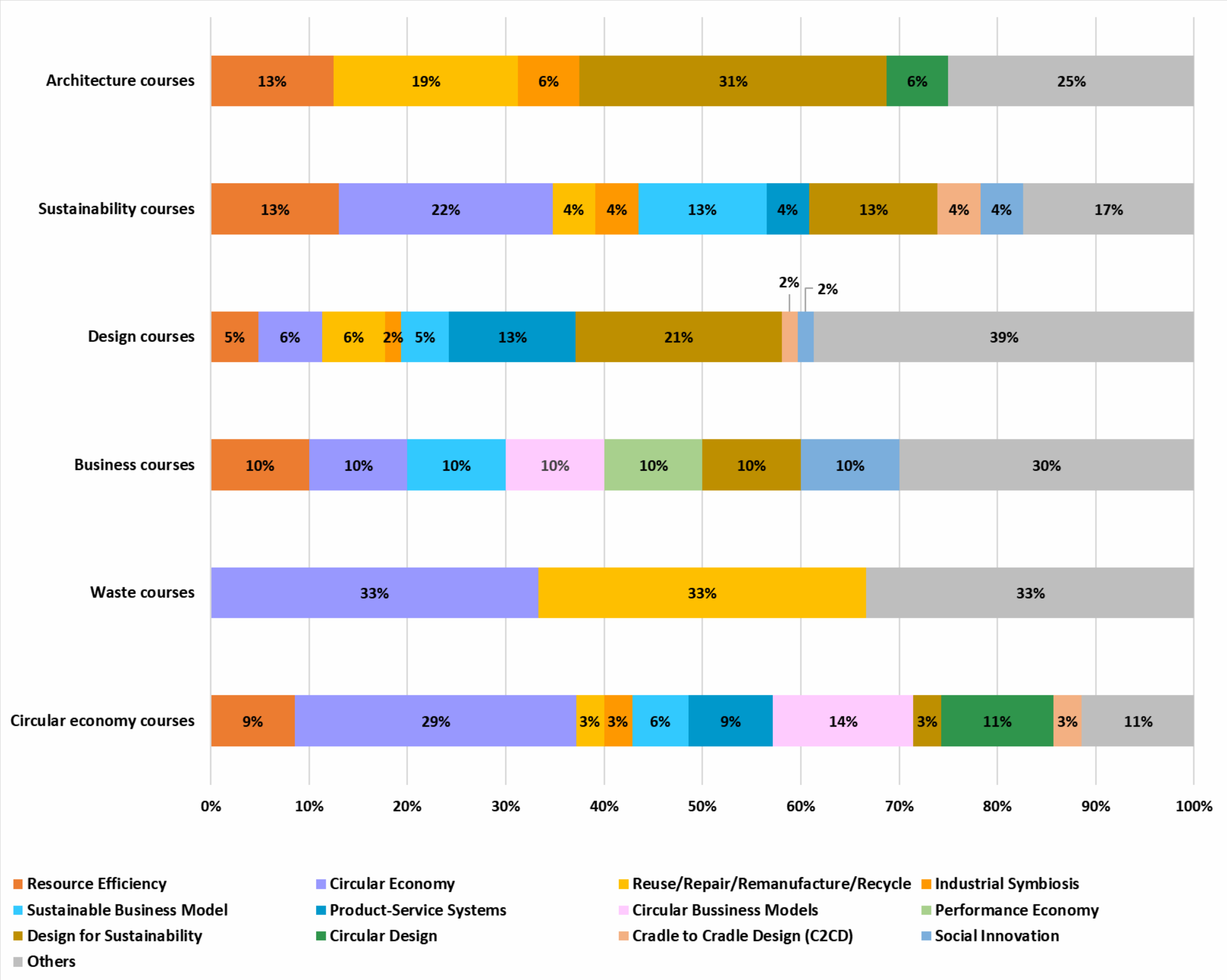

Figure 2. *Topics related to CE present in subjects and disciplines (here broadly designated as "courses") offered in HE.*

In order to have direct testimonies from the main stakeholders, a series of interviews and several workshops were conducted. The target groups addressed were students, professors, researchers, companies, business associations, public authorities and NGO's. The answers of 49 interviews and the main findings from the workshops were classified in seven main topics, as described in the following paragraphs.

Understanding and perceptions of circular economy

The concept of CE is still not clear and harmonized. The variation in understanding and perception was identified as a possible barrier to CE implementation.

The most common concepts used to describe CE are those shown in figure 3. It was observed that the majority (25%) corresponds to the terms "reuse" and "recycling"; and the relationship between CE and social aspects is very rare in the responses.

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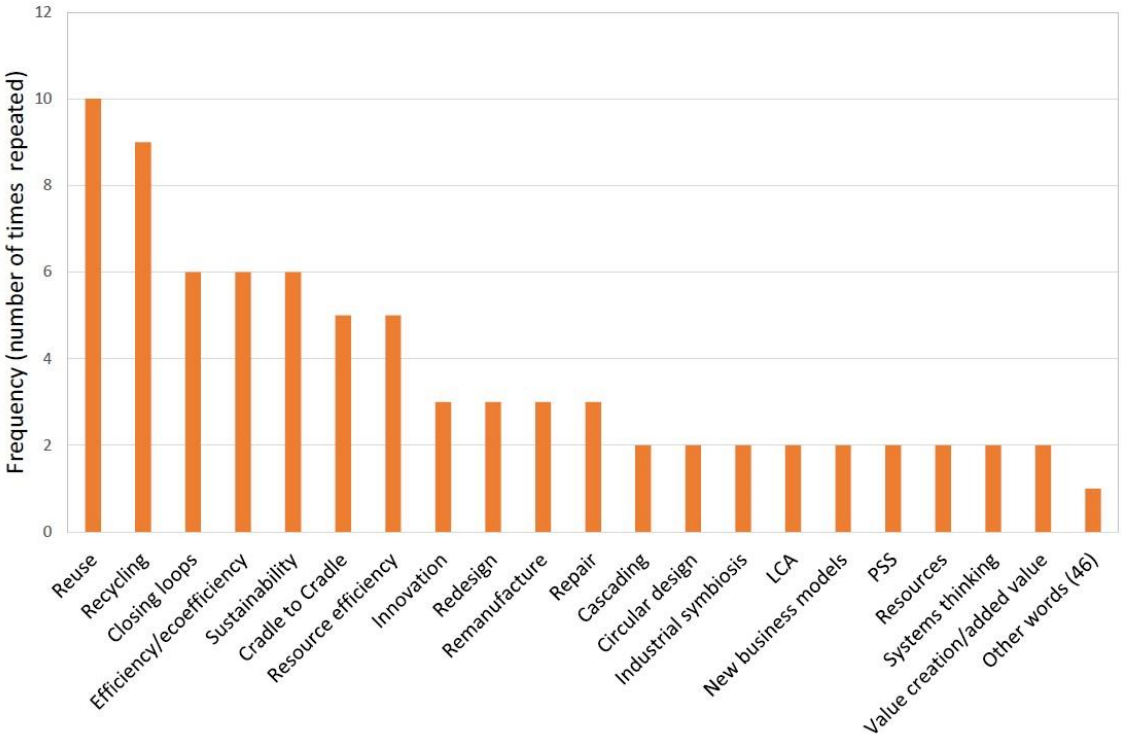

Figure 3*. Frequency analysis of the answers to the question "What three words would you say best describe CE?"*

CE implementation and promoting actions

Teachers and students demand CE training and implementation in the curricula in a more systematic way. Companies are more optimistic when declaring to apply CE strategies than universities.
Regarding promotion of CE, different perspectives were found according to the type of actors: Administration claimed to do an important effort, but that effort seems not being perceived by business associations.

CE: Demands and needs

The needs and demands for the transition towards a CE were mainly related to financial support for investments, new business models, and the need to adapt legislation and infrastructures.
The needs and demands for competences related to CE requires skills to solve problems involving more than one stakeholder, with pragmatic tools and methods and multidisciplinary knowledge, which should support fast real-life changes.

Main drivers to CE

The main drivers identified (in order of relevance) are: legal/policy; education/awareness; environment pressure; business/financial; consumer/market; innovation; and younger generations. Figure 4 shows the main drivers identified by the different target groups at present and in the future

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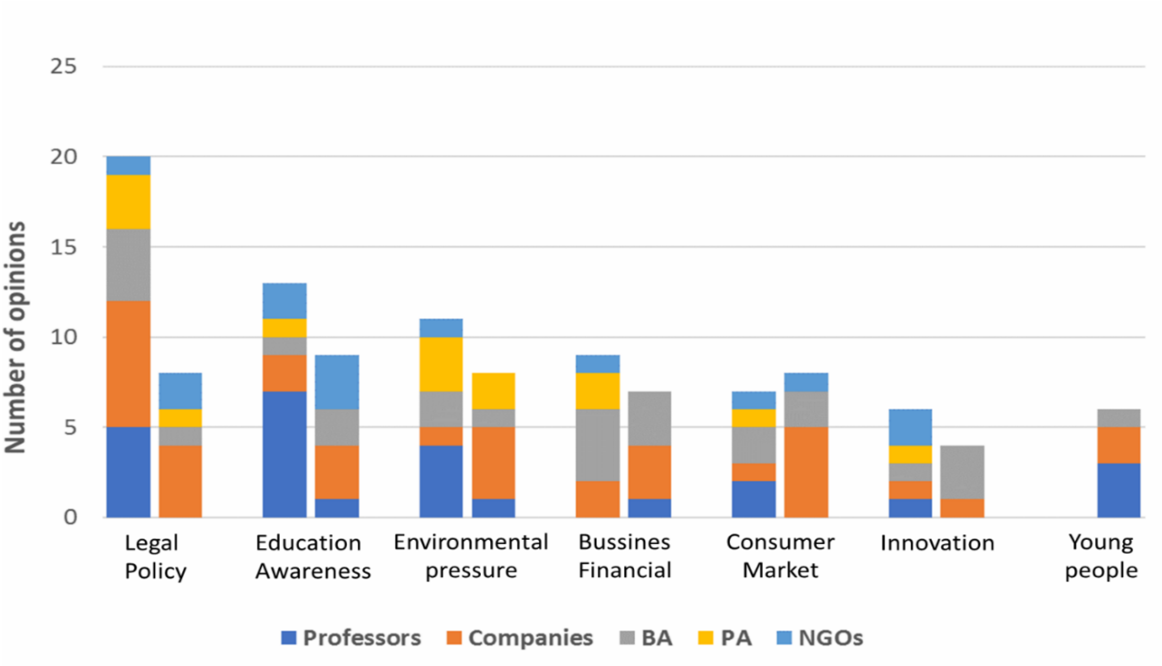

Figure 4. *Present (left column) and future (right column) main drivers, according to the different target groups interviewed: Professors, companies, business associations (BA), public administration (PA) and non- governmental organizations (NGOs)*

Barriers in implementing CE

Lack of commitment, time, knowledge, skills and competences were common barriers to implement CE in universities and companies.

At universities: difficulty in introducing new contents in curricula and multidisciplinarity. At companies: inability to adapt to developments and changes of new products, services and business models, low demand from market and legal barriers (e.g. waste classification)

Challenges

From companies` point of view: keeping up with developments and trends, ensuring to adjust the portfolio to the demands of the market and environmental legal requirements. From educational point of view: keeping up with developments and trends, thinking and acting in an interdisciplinary manner and as a service-provider, qualifying future CE experts.

In summary, all these findings were used as a basis for discussing and proposing the necessary competencies to be addressed by KATCH_e, to foster their implementation at the higher education level with pragmatic methods and tools. The applied methodology guaranteed a holistic and multidisciplinary approach, ensuring that key findings, relevant aspects and recommendations were included.

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4 Stakeholders' engagement

Stakeholder Engagement activities were, and are. planned for and conducted throughout the project period in all four countries and in international fora. The purpose was to include the stakeholders' knowledge and recommendations in the development of the training materials, and at the same time disseminate information and create interest for the outcomes of the project.

In the first project phase, relevant stakeholders representing the three main target groups, Higher Education, Business community and Knowledge Centres, and key players within authorities, NGO's etc. were contacted, and around 50 people were interviewed as a part of the training needs analysis. Later, while defining the content of the KATCH_e modules, key stakeholders with knowledge and experience on circular economy were involved in reading and commenting. Their valuable feedback informed the decision-making on what to include and explain in the training materials.

In the later phases of the project, stakeholder engagement was used as a part of testing and using the training materials, and in building the knowledge alliances that will support after-project activities and use of the KATCH_e materials.

Through the project period, stakeholder networks were established in all four countries with a total number of members well above 400, and the networks continue to grow. All members receive the KATCH_e newsletter and information on the project and key stakeholders are actively involved in different ways. For example through participation in the series of workshops taking place during the project period. Table 2 presents an overview of these workshops.

***Table 2**. Overview of the national KATCH_e workshops*

	Theme	**Period**	**No. of participants**
Workshop I	CE training needs	Spring 2017	100
Workshop II	Use and feedback on KATCH_e materials	Winter 2018	150
Workshop III	Evaluation and future cooperation	Autumn 2019	-

Moreover, three international workshops serve to present and discuss the project with experts and professionals in a wider setting outside the four countries:

4.1 Workshop on ERSCP (European Roundtable on Sustainable Consumption and Production) 2018 to discuss the intended content of the training materials

4.2 Workshop and presentations on ERSCP 2019 to present and discuss the KATCH_e training materials and how to use it

4.3 Workshop on SEFI (European Society for Engineering Education) conference 2019 with hands-on experiences for the participants.

Finally, a Knowledge Hub is organized on Linked In to stimulate the debate on training for circular economy.

5 Development of the training materials

Introduction to the development process

The KATCH_e training materials were developed based on the exhaustive analysis of the state of the art and existing training resources collected within the situation analysis, together with the involvement of the stakeholder network. They are meant to be used in academic teaching, in-classroom context, as well as in companies or workshop settings, and comprise eight KATCH_e learning modules and seven KATCH_e tools that support the practical implementation of the knowledge acquired with the modules.

The focus of this project is to facilitate the process of integration of CE aspects in the design process of products and services. Nevertheless, as seen in section 1.3, the CE represents a new way for companies or producers to create value compared to the more traditional linear business model of production, where profit is generated from selling products (Bocken et al., 2016). This calls for the development of new business models such as product service systems, leasing, collaborative consumption, sharing platforms and business models based on maintenance and repair (Bocken et al., 2016). Stahel also introduced in the 1990s the functional service economy with the purpose of selling performance instead for a selling a product (Stahel, 2013). CE is also linked to the sharing economy, where the consumer buys access to a product instead of owning it (Hobson and Lynch, 2016).

With these ideas in mind, the themes of design and business models are central in the KATCH_e results. Moreover, transformation towards more circular products and businesses requires information about inputs and outputs of systems and processes, measuring their impacts, as well as management of data and data exchange across the value chain. Following this understanding, the modules and tools have been developed according to a framework organized in four main areas:

5.1 Basics: Basic knowledge on CE that supports the understanding of the other materials;
5.2 Business: The business approach, required for the success of new, more circular and sustainable products or product-service;
5.3 Design: Product and product-service system design according to circularity and sustainability criteria; and
5.4 Assessment and communication: A support area with contents regarding assessment and communication in circular economy with a life cycle perspective.

The following table (3) presents the framework and the relation with the modules and tools.

Table 3. *KATCH_e modules and tools*

Framework	Modules	Tools
Basics	— Introduction to the circular economy	— KATCH-Up Board Game
Business	— Business models — Value chains	— CE Strategist — CE Value Chains
Design	— Processes and materials — Design and development — Radical innovation and collaborative design processes	— CE Designer — CE Journey
Assessment and communication	— Life cycle perspective — Communication	— CE Analyst — KATCHing Carbon

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The modules and tools aim at approaches that promote innovation at HE, the two most important being:

5.5 Privileging problem-based learning (PBL), where students are presented with a problem and engage in
5.6 active learning in the sense that they have to discover and work with content which is necessary to solve the problem.
5.7 Multidisciplinary, which is inherent to the thematic of CE and sustainability: while we focus on product development, we are not limited to design / product design / industrial design education. Other disciplines such as engineering (mechanical, materials, chemical, environmental), environmental sciences, marketing and business and innovation management will be involved.

All materials were tested and validated with the involvement of several stakeholders, in pilot projects and training initiatives carried by the consortium, seeking a high quality of the resources. These phases are presented in the next sections.

Testing and validation of the training materials

The development of the training materials had an iterative nature also before the testing phase due to the interaction with external stakeholders, students and companies. After the completion of the draft versions of the modules and tools the testing phase that took place in parallel in the four project countries provided valuable insight regarding quality and applicability. It included face-to-face classes, workshops, etc. at universities and internships in the partner companies and delivered valuable feedback to improve and update the materials and the tools that has been gathered through the established evaluation mechanisms. After completion of the Massive Open Online Course (MOOC) in fall 2019 it will also be tested.

The universities played a key role in testing the modules and tools and managed the interaction between students and companies through internships. The intensity and workload for professors and students varied depending on the laid focus, e.g. at one university a semester project was performed, at another a new multidisciplinary course on circular design was introduced while at other university only parts of the materials have been integrated in existing courses or students had to perform self-study and implement selected approaches on their assignments or final thesis. Via external lectures and workshop activities, additional universities, companies and organizations could be involved.

Besides gaining feedback on practicability and relevance of the developed materials for various disciplines and sectors the testing also lead to case studies resulting from the internships of students in the partner companies and conducting of bachelor and master thesis. The results developed by students tutored by professors create direct benefits for the involved companies:

5.8 Evaluation of the status of the business strategies on CE
5.9 Accustomed business strategies towards CE
5.10 Innovative product/product-service concepts

The implementation of the strategies and concepts is not mandatory to the companies and lies out of the scope of the project. Nevertheless, the results from the testing phase will stimulate changes within the project partners. Respecting confidentiality requirements set by the companies the results will be open to public in the knowledge centre of the project webpage in order that they may inspire others.

First findings and conclusions have been presented and discussed at the second national stakeholder workshops and pedagogic materials for the future application in various university and company settings will be constituted.

Evaluation of the training materials

In order to identify whether the training materials and tools meet the objectives of the project and the needs and expectation of the users of the resources, the consortium developed an evaluation methodology. The stages defined for this purpose are:

5.11 Definition of the evaluation needs

5.12 Design and development of the evaluation procedure

5.13 Application of the evaluation procedure and analysis of results

5.14 Evaluation of long-term indicators and outcomes

To this date, the first two stages have been completed, and are presented in this section, together with preliminary results of step 3.

Hence, the first step of the evaluation procedure was to establish the evaluation needs of the project:

5.15 How suitable are the training materials?

5.16 To what extent do the materials promote the CE?

5.17 How clear are the materials?

5.18 Degree of satisfaction with the contents.

The evaluation procedure (step 2) was based on questionnaires, and two types have been developed: one to be filled in by the people who have read or applied the training module or tool, typically professors (Type A) and another to be filled in by the trainees who were exposed to the module or tool and a learning environment, such as a lecture or a workshop (Type B).

Table 4 summarizes the type A questionnaires for the modules and for the tools. Given the explanatory character of the former, the related questionnaires are much more comprehensive than the latter. And since the learning objectives specified in the modules were part of the evaluation criteria, there was one questionnaire per module, unlike what happened with the questionnaires for the tools.

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Table 4. *Contents of the type A questionnaires.*

Type A questionnaires for modules	Type A questionnaires for tools
Identification of the respondent and date	
Whether or not the full module was tested. If not, which chapters?	
Performance of the module in view of the learning objectives (semi-open question with a field for justification	
Opinion on the module or tool (semi-open question with a field for justification or improvement suggestions):	
— The language of the module is adequate — The content is understandable and well structured — The text is versatile enough to be applied in all target groups — The module has a practical and didactic approach — Additional reading was needed to understand the module — The assignments are relevant — The examples are relevant	— The tool is intuitive and easy to understand — The tool is easy to apply to real practical cases — The results make sense and are easy to understand — The results are in accordance with the time and effort to use it — The results are useful and applicable to the development of new products and services
Open questions regarding what the respondent liked and disliked the most about the module and suggestions for improvement.	

As for type B questionnaires, they were filled in by trainees, online or on paper. These questionnaires are presented in table 5.

Table 5. *Contents of the type B questionnaires.*

Type B questionnaires for modules	Type B questionnaires for tools
E-mail address of the respondent and date	
Name of the respondent (optional)	
Module/Tool (closed question, multiple choice)	
Degree of previous knowledge about the content of the module (closed question, 3 points scale – low, medium, high)	
Opinion on the module or tool (open questions):	
— Which content did you find more interesting? — Which content did you find less interesting? — Which content did you find confusing? — How did you like the assignments? — Suggestions for improvement	— Is the tool intuitive and easy to understand? — Is the tool easy to apply to real practical cases? — Do the results make sense and are easy to understand? — Are the results are in accordance with its time and effort of use? — Suggestions for improvement

Once the questionnaires were designed, each partner had an assigned number of tests to carry out about (a) specific module(s) and tool(s) (see the previous section). They chose the adequate professionals, companies, institutions or students to do so, depending on the target group of the tester and the kind of content of the module or tool that was going to be tested. Then, the compilation of the evaluation forms and questionnaires was organized and all the evaluation information was merged and analysed. As an example of the evaluation results, a summary of strengths and weaknesses of the modules is presented in table 6.

Table 6. *Excerpt of the evaluation of the modules: strengths and weaknesses.*

Type A questionnaires	Type B questionnaires
STRENGHTS	
— Brief definitions, clearly explained contents, even for non-experts — Key words & summary tables help understanding — Reference to further reading — Good, illustrative & helpful examples — Tools very relevant for companies' use — Clarifying figures, images and tables — Different, reflective, adequate assignments to consolidate contents	— "Assignments make us think creatively" — Very useful concepts and tools to apply in design — Debates / discussions are positively valorated to learn from others' points of view
WEAKNESSESS	
— More detailed instruction of how to complete the assignments is needed — Not enough examples to consolidate theoretical concepts — Explained case studies needed to understand concepts — No mention to other modules — Some assignments difficult to understand — More explanation on some figures needed — Better description of tools desired — Too theoretical, more graphics desirable — How to put that theoretical info into practice is not clear — More detail needed for professionals' target group	— Too much information: More visual and attractive presentations needed — They need time to assimilate concepts to apply them in the assignments — More real life examples welcome — More practical examples — Clear instructions and guidance in assignments desired

Through the evaluation procedure, it has been possible to register and collect valuable feedback from the people who have tried the materials or who have been trained with them. They have been very useful to show to what extent the materials and training generated in the project meet the project objectives, to depict how far has the material helped to increase the CE knowledge, as well as to display how the contents are applicable in the real context of the companies. Moreover, the feedback was used to further improve the materials.

6 Results

The KATCH_e results are available for free on the project website (www.katche.eu), where users can access the Knowledge Platform (KP) upon registration. The KP hosts all educational resources produced within the project:

6.1 Tools and training materials:

- 6.1.1 KATCH_e modules
- 6.1.2 KATCH_e tools
- 6.1.3 Didactic recommendations targeting HE institutions willing to use the project's materials
- 6.1.4 Glossary

6.2 The KATCH_e online course, with a duration of 10 hours (MOOC)

- 6.2.1 Overview of the modules (video and table of contents)
- 6.2.2 Narrated presentations of the KATCH_e modules
- 6.2.3 Links to the KATCH_e tools with a short tutorial
- 6.2.4 Links to the case studies

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6.2.5 Quizzes

6.2.6 Final exam

6.3 Other materials

6.3.1 Case studies that resulted from the internships in partner companies

6.3.2 Business strategies on CE from the partner companies

6.3.3 Database of examples of the implementation of CE strategies in the target sectors

6.3.4 Situation analysis report and executive summary

6.3.5 The 10 Essentials of working with circular economy

6.3.6

In the next sections the modules and tools, which were the most innovative and comprehensive results of the project, will be presented.

The KATCH_e modules

The testing and evaluation phases allowed for many suggestions for improvement to be integrated in the final versions of the KATCH_e modules.

Each module begins by asking a main question which acts as a guide for readers/users. Modules are organized into chapters and include various assignments and examples to support teachers and trainers in preparing training sessions, or as a self-learning exercise.

There is no predetermined order and each module can be used independently, except for the "Introduction to the Circular Economy" module, which should be the first, especially for someone unfamiliar with the concept of CE. However, each module includes an indication of the required prior knowledge, which may have been obtained elsewhere or through another KATCH_e module. This independence character is illustrated in figure 5.

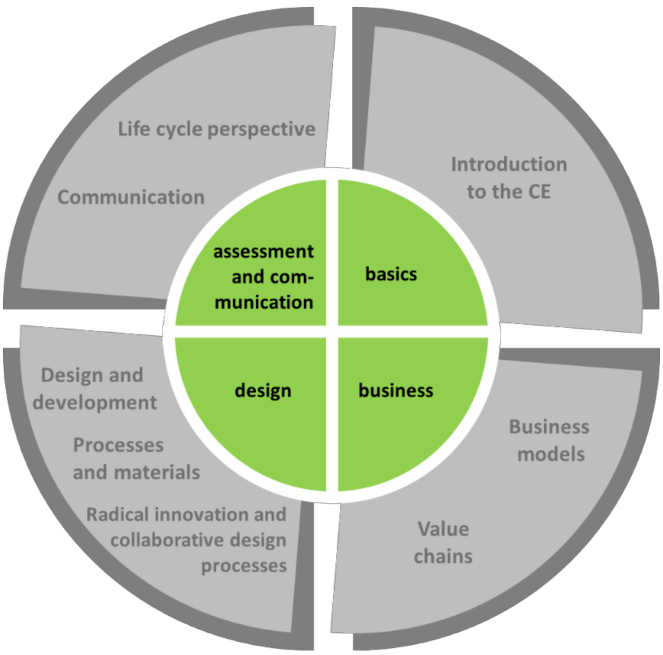

Figure 5. *KATCH_e modules*

The four areas' framework was kept, as shown in the figure. The modules vary in length, between 51 and 85 pages and follow a common organization:

6.4 Learning objectives

6.5 Previous knowledge (recommended, cross-referencing other KATCH_e modules)

6.6 What (is the module about), who (would be interested), where (in which context does it make sense to read it), when (does it apply in the development process), why (is it relevant) and how (can the knowledge be applied)

6.7 Questions the module addresses

6.8 Executive summary

6.9 Main chapters (with assignments in all chapters)

6.10 Examples

6.11 Bibliography

Besides, in all modules the most important terms and expressions are highlighted and available in an online glossary. An image of the cover page of one of the modules is shown in Figure 6.

***Figure 6**. Cover page of the "Introduction to the Circular Economy" module.*

Table 7 provides an overview of the contents of the eight modules.

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Table 7. *Overview of the KATCH_e modules*

Module	Main question the module addresses	Contents (main chapters)
Introduction to the circular economy	What is CE and what is needed to work from a circular approach?	- The global sustainability challenge and why we need a new approach to production and consumption - Defining CE and the underlying principles and strategies - CE in the construction and furniture sectors - Design and innovation for a CE - CE requires new business models - Main challenges and drivers in shifting to a CE - EU policy and legislation for CE - Sustainable production and consumption - CE in the construction and furniture sectors - Tools for introducing the CE - The 10 essentials of working with CE

Module	Main question the module addresses	Contents (main chapters)
Business models	How can companies work towards the aims of CE by adopting circular strategies within their business model?	- What is a business model? - The circular business model - Revenues and costs – financial implications of CBMs - From linear to circular business models
Value chains	How should value chains and value networks be understood and managed to get benefited from a CE?	- Introduction to the concept of circular value chains and networks - Why change to a circular value network? - How to optimize supply chains through reverse networks - Business strategies/models that support the implementation of circular value networks - Stakeholders engagement and management: how to establish a circular value network - Existing tools for the management of value chains towards sustainability
Processes and materials	Which are the most relevant characteristics of materials and processes to carry out CE strategies for product and product service development?	- Contextualization of the role played by processes and materials in CE - Characteristics of materials and processes from a CE perspective - Design and development strategies vs. characteristics of materials and processes

		- Compilation of processes and characteristics of materials examples and references - Possible trade-offs (and some methods used to deal with it) when making decisions and creating potential contradictory effects
Design and development	How can the design of products and services contribute to the CE?	- Concept: From ecodesign to design for the CE and sustainability - The role of design in CE - KATCH_e design strategies for a CE - Product and service design step-by-step - Design for CE in the building sector - Tools for product and service design for CE - Examples and case studies
Radical innovation and collaborative design processes	Considering the impacts of the design activity on industry and society at large, how can radical innovation change behaviours and mind-sets, specially related to sustainable consumption and environmental education?	- Introduction to innovation - CE as an input for the innovation process - Product-service system design - Collaborative and participatory design for innovative processes - Open-source as a mean to feed innovation and disseminate results
Life cycle perspective	What information is needed to assess circularity along the life cycle of products or services?	- Introduction to life cycle thinking - Impact assessment along the life cycle - The life cycle of products and discussing circular loops - Assessment & communication on building and component level - Case studies of construction and furniture products
Module	**Main question the module addresses**	**Contents (main chapters)**
Communication	How could the advantages of circular products and services be communicated?	- Introduction to communicating circularity - Guidelines and techniques for communicating circularity - Specific circular communication tools - Environmental labelling and product declarations and their relation to CE - Examples of circularity communication in the furniture and construction sectors

Most of the modules' contents is applicable to any kind of products. Sector-specific contents have been included and the examples are related to the construction and furniture sectors. They are included in the modules and available online in a database.

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The KATCH_e tools

The tools are developed with the intention to complement the theoretical inputs of the modules. However, the tools also stand on their own and can be applied individually without the background information in the modules. Figure 7 shows an overview of the seven developed tools and their relationship to the defined framework

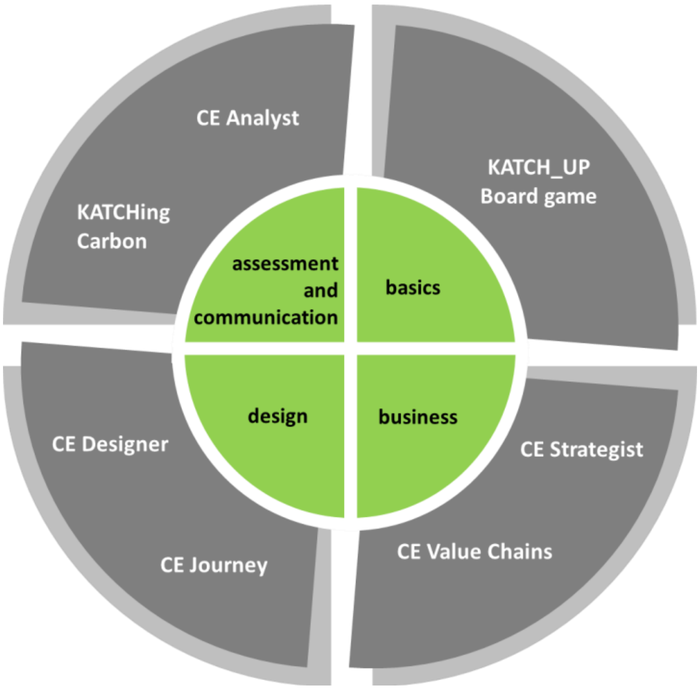

Figure 7. *KATCH_e tolos*

The term "tools" within KATCH_ e refers to a wide range of different practice-oriented instruments. The seven tools developed consist of three webtools (which will be available under www.katche.eu), two Excel-based tools, a board game and a workshop-template for visualizing CE potentials.

The three webtools – the CE Designer, CE Strategist and the CE Analyst - are developed as an interlinked package uniting the three major issues of the KATCH_e-framework showing how CE strategies affect the product design, the business model and the environmental product profile.

Table 8 summarizes the tools purpose, results, method and platform. The tools are currently in the process of being evaluated, tested and adapted. The final versions will be available at the end of the project period (12/2019).

Table 8. *Overview of the KATCH_e tools*

Tool	Platform	Purpose	Methodology
CE Designer	Webtool	semi-quantitative checklist-tool for prioritization, assessment and idea finding of circular solutions for product	— Choose the most relevant CE-Strategy for a specific reference product — Evaluate the fulfilment of the corresponding criteria — Define potential design improvements — Compare the improved version and the

		and/or service (re)design	reference product
CE Strategist	Webtool	Identify Circular Business Opportunities and provide guidance along the Business Model Design process	— Describe the current Business Model with a Business Model Canvas (BMC) Template (optional) — Evaluate the applicability of predefined CE Business Strategies — Learn from examples and choose the best-fitting strategy/strategies) — Define the (adapted) CE-oriented Business Model with the help of highlighted influences related to the chosen strategies
CE Analyst	Webtool	Quantitative LCA-based tool to estimate the impacts of CE strategies on its carbon footprint	— Enter the Product Carbon Footprint (PCF) data of a "linear" reference product system for all life cycles — Evaluate and compare the potential to reduce carbon emissions through different CE Strategies and choose one — Estimate the impacts through the corresponding variables — Repeat the previous two steps with a different strategy or compare the PCF of different product systems
Value Chains	Excel	Prioritization and identification of external and internal stakeholders for a specific CE strategy	— Map current stakeholders and assess their relevance — Identify new stakeholders needed for the CE project — Assess all stakeholders according to their relevance and capacity and interpret the resulting scatter plot — Define an action plan

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CE Journey	Printable Canvas with Cards	Visual representation of the material- and stakeholders- “journey” of a Product- or Service- system over its the whole life cycle	— Preparation (define the product system, gather materials and groups) — Assign roles to the participants (Materials, Producer, Partner, User) — Pick a set of “Superpower”-cards according to the assigned role and discuss the questions on it and fill it out — Pick a set of “Challenges”-cards according to their assigned role discuss its questions and fill it out — Fill out the Canvas with pins and threads; identify touchpoints and reflect on them

Tool	Platform	Purpose	Methodology
KATCH-Up	Board Game	Generation of CE-inspired Ideas for predefined challenges	— Preparation (print board and cards, gather groups of 3 to four people) — Scenario-phase: Pick a problem-context card with a specifically defined CE challenge — Idea-phase: Pick one design card and the corresponding business card — Planning phase: Define a Business Model with available templates — Presentation: Present the idea and score the others
KATCHing Carbon	Excel	Product Carbon Footprint (PCF) Calculation	— Easy to use Product Carbon Footprint calculation for products from the building and furniture sector — Data input along the five life cycle phases raw materials, manufacturing, distribution, use and end- of-life — Results can be used for the CE Analyst tool

7 Conclusions and further developments

It is perhaps too early to draw conclusions since the KATCH_e consortium is still deeply involved in finalizing all the project's results, and there are many, more than those promised in the application. One of the reasons for this, something the consortium views as a success, is the very high interest this project raised in the four countries. From the beginning, partners were aware that Austria and Denmark were ahead of Portugal and Spain in the field of CE. Nonetheless, formal stakeholders and other interested parties from the four countries got proactively involved in KATCH_e, and this was particularly visible in the extensive testing that was performed. Often, it was the stated interest of professors, business associations and others that offered the possibility of performing an extra

lecture, offering the materials for test or conducting a new workshop, beyond the initial plan

Since the start of the project in January 2017 many educational resources, reports, scientific publications, legislation etc. have been published or are in preparation. The CE topic has not lost momentum and the main aim of the KATCH_e project, to produce training materials and practical tools to be integrated in HE and in business environments, is still valid. Although not as systematically as in the situation analysis phase, the consortium observes there are many gaps to be filled in when it comes to education and training in CE. Therefore, the exploitation of the project's results after the funded period is crucial for the achievement of its goals in the short and in the long terms.

Therefore, an exploitation plan has been co-created by KATCH_e partners and national stakeholders participating in the project from the beginning. This plan establishes the route that each partner will follow for an efficient exploitation of results at regional, national and European level after the project conclusion.The continuous contributions received from the four national stakeholders networks' members have been essential to define the steps to follow throughout and beyond the project. The activities and the partnership will be sustained beyond the project lifetime with the aim of maintaining its results and to keep the exchange of ideas and experiences on CE among stakeholders, by enhancing its know-how, financial and human resources. Additionally, the project website, the Knowledge Hub and Knowledge Platform will be kept alive by core partners and other relevant stakeholders, at least for the five next years.

The valorisation of the KATCH_e results will take place at four different levels: educational level, company level, research level and European level. Indeed, KATCH_e results are going to be used not only by project participants, but by their stakeholders networks, the educational organisations that will deliver the KATCH_e contents to their students, the business organisations, business clusters, chambers of commerce as well as research and technological centres that will disseminate the contents among their members. This way, the KATCH_e course, modules and tools, case studies and other innovations will be useful tools to train, encourage, make aware and spread CE approaches to a larger academic community, business and expert community, institutional bodies and public in general.

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which may be made of the information contained therein.

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Circular Economy

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The discourse of power in perceptions of risk in transitioning to a circular economy for UK SME manufacturing

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Abstract

The aim of this paper is to understand the ways that sense is made of SMEs decisions relating to transitioning to a circular economy in the manufacturing regime. By using discourse analysis to investigate what is currently understood of the realities of transitioning to a circular economy for SMEs, and why those understandings exist, we can identify if there are additional ways of unlocking circular economy potential in manufacturing and how future interventions and discourses may need to change. This paper presents the analysis of spoken data collected through interviews with decision-makers in manufacturing SMEs and individuals representing organisations in the wider manufacturing regime network of influence. Using a structured, iterative six step analytical framework, that combines constructivist grounded theory strategies and a critical discursive psychology perspective, this paper presents the analysis of the dominant pattern of discourse "*if the bigger fish say*" associated with understandings of the power dynamics in SME-customer relationships. The pattern was found to predominantly be used to position SMEs, due to their size, as powerless to act independently. The discourse presents SMEs as being part of a hierarchy in an established 'authoritarian' manufacturing regime where they are culturally and historically positioned as subordinates, expected and obligated to react to customer demands, primarily on cost. The analysis has also shown that this obligation has become an embedded understanding in the manufacturing regime and influences perceptions of risk for SMEs. Engaging in activities to support a transition to a circular economy, whether voluntarily or demanded by customers, were perceived as a risk object for SMEs as such actions are understood to act against expected cost-centric commercial obligations on SMEs. The obligations result from SMEs becoming locked into technical, resource and financial path dependencies that have been created and enforced through the power of customers designed to serve their own best interests. We conclude that the discourse of power in transitioning to a circular economy indicates that we are in a deadlock situation with the ability to transition to a circular economy constrained where policy relies on SMEs gaining expert power as the solution to transition and neglects the mechanisms that underpin the structural power of big business, public sector and consumer publics.

Keywords: Circular Economy, Risk, SME, Discourse, Psychology

1. Introduction

The recent decade has seen increasing popularity in academic and policy circles of the concept of transition to alternative production and consumption systems such as a circular economy, aimed at decoupling economic growth from increasing material consumption through slowing or closing material resource loops (Geissdoerfer et al., 2017; Prieto-Sandoval, Ormazabal, et al., 2018). Research has primarily involved investigating definitions and conceptualisations of the circular economy (e.g. Ghisellini et al., 2016; Kirchherr et al., 2017; Lieder & Rashid, 2016; Millar et al., 2019), business models and case studies or niche innovations (e.g. Bassi & Dias, 2019; Bocken et al., 2014; Bressanelli et al., 2017; Whalen, 2019), surveys (e.g. Gusmerotti et al., 2019), measurement indicators (e.g. Moraga et al., 2019) and investigating the demand side, consumption-related aspects of the system (e.g. Cherry & Pidgeon, 2018; Hankammer et al., 2019).

However, there is criticism of the circular economy, especially in relation to the ability to decouple economic growth from consumption (Charonis, 2013; Homrich et al., 2018; Korhonen et al., 2018) or to result in substantial reductions in material use, environmental, social and climate change impacts (e.g. Manninen et al., 2018; Nußholz, 2017; Zink & Geyer, 2017).

Such criticisms are based on an understanding that the current techno-economic focus of research and policy continues to lock in and reinforce the existing linear economy ideology and production and consumption sociotechnical regime. Social dimensions that embed the way we think about the circular economy, including values, societal and institutional structures, cultures, shared understandings, meanings and underlying world-views, remain generally unacknowledged or under-researched (Geels et al., 2017; Stewart & Niero, 2018). Failure to acknowledge the influence of these dimensions can undermine transition aspirations in policy, such as experienced in the UK regarding onshore wind, the Green Deal, Zero-carbon homes and the current smart meter roll out (Geels, 2018).

The aim of the research in this paper is to better inform understandings of the social dimensions of the circular economy through investigating discourses. The focus is on SME manufacturing businesses, small and medium sized enterprise employing between 10 and 250 people, who carry out the majority of manufacturing in the UK but are usually hidden deep within the manufacturing regime, supporting generally globally large brand businesses. Due to this lack of visibility, assumptions are made about SMEs with very limited attention on what such SMEs understand of transitioning to a circular economy and how they're perceived by networks of actors in the manufacturing regime to be part of transition. The research in this paper aims to provide such insights investigating the discourse of power in SME-customer relationships and how this influences perception of risk in transitioning to a circular economy.

1.1 Business decision-making and risk

Manufacturing businesses are perceived to have the ability to change what and how materials are used, how products are designed and produced and how they are provided in society (Prieto-Sandoval, Jaca, et al., 2018).

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Change will require decisions to be made and given that the concept of risk is often seen as intrinsic or an important facet of decision-making in business (Helliar et al., 2001; Lark & Nikonov, 2015), understanding the influences on perceptions of risk for SMEs will help inform how change can be orchestrated.

For this research risk is understood to be a construction (Brivot et al., 2017; Hillson & Murray-Webster, 2004), being a subjective, culturally and socially embedded construct of individual and collective thought (Boholm, 2003; Slovic, 1992; Vasvári, 2015). On this basis, this paper acknowledges there is a wide range of influencing dimensions, both objective and subjective, of risk perceptions and adopts a relational theory of risk perspective taking account of risk objects (sources of potential harm) and potential objects at risk (Boholm, 2003; Boholm & Corvellec, 2011; Langley et al., 1995; Slovic et al., 2004). Such an approach aims to recognise the complexity of the manufacturing regime, the taken for granted understandings, and the range of influences on individuals involved in decision-making and thus how people come to evaluate risk for different situations, or the same situation (Horlick-Jones & Prades, 2009; Renn & Benighaus, 2013).

1.2 Discourse

To gain insight into understandings and the taken for granted requires interaction with the manufacturing regime. A primary interactional mechanism is discourse, with much of what is achieved in society being enabled or constrained through discursive practices. Discourse enables ideas, knowledge, feelings and experiences to be shared, understandings of the world developed and communicated, and meanings given and reinforced to aspects of the world (Phillips & Jørgensen, 2002). In this research, discourse is understood to be constructed of existing discursive devices and both representing and constructing reality, in which meanings associated with aspects of the world are not fixed, are transient and subject to change, being historically, socially and culturally variable (Billig, 2005; Potter, 2009; Taylor, 2001). Discourse is also both performative and political, by redefining or specifying truths, rules, action, power, the right knowledge and the relative importance of different actors, and is often deployed by actors to achieve something in a specific context (Georgaca & Avdi, 2011; Nyberg & Wright, 2016). However, what is understood of a concept is considered to be fluid in that people potentially have different or multiple accounts of the same phenomena and as such discourse is taken to be more than a reflection of reality (Dryzek, 2005). This does not mean reality does not exist, but what is understood of reality varies and can change and it is the understandings of the conditions in the world that are important in decisions. By investigating what is currently understood of the realities of risks in transitioning to a circular economy for SMEs and why those understandings exist we can identify if there are ways of unlocking current thinking and practices and what this means for the future of actions to instigate change in production and consumption.

Methods

Discourse analysis is central to this research. Given there is not a unified, singular approach to analysing discourse, being interdisciplinary and applicable to a wide range of theoretical traditions (Howarth, 2000; Wetherell et al., 2005), a critical discursive psychology (CDP) approach has been purposively chosen for this research. Although discourse analysis traditionally focuses on how discourse as action defines social reality (Burr, 2015; Sims- Schouten & Riley, 2014; Wood & Kroger, 2000), there is a growing interest in recognizing that entities beyond discourse, and their associated structures in the world, also condition discourse of social reality (Flatschart, 2016; Georgaca & Avdi, 2011; Morgan, 2010; Sims-Schouten et al., 2007). Entities can be material, social, political or cultural systems with associated formal and informal rules and practices that exist and have real effects in reproducing or transforming the enabling or constraining conditions for action, whether interacted with purposefully, consciously or otherwise (P. K. Edwards et al., 2014; Fletcher, 2016; Maxwell, 2012). Therefore, the study of discourse from a critical perspective, such as the adoption of a CDP approach, can provide both interpretative explanations of why particular phenomena exist and what is being done through discourse.

CDP works within the tradition of discursive psychology focusing on the function of psychological themes (e.g. motives, perceptions, responsibilities, beliefs) and the action orientation of discourse (Potter et al., 2007; Potter & Wetherell, 1987), rather than looking to identify individuals' views on a topic or to understand individuals mental entities such as attitudes (D. Edwards, 2005). However, CDP also looks to identify the extra-discursive entities and structures in the world, that may or may not be interwoven with discourse, and their relationship and interactions in these discursive practice (Sims-Schouten et al., 2007).

2.1 Data collection

Discourse exists "out there", and is itself an entity that has the ability to embody power and to condition understandings, beliefs and values of people, advancing and suppressing interests (Dryzek, 2005), as well as being able to be generated for research through interaction with individuals. Although both available discourse (e.g. published text) and generated discourse data from one to one interviews will be included in the overall research, this paper is based on 11 in-depth semi-structured interviews carried out face to face or by telephone/ video chat between March and November 2018, representing different types of institution operating in the manufacturing regime. The interviews were purposefully structured to be conversational style, lasting around an hour, using a topic guide where the flow of the conversation was largely dictated by the participant with the researcher interjecting to maintain focus on the specific topic being discussed.

2.2 Sampling strategy

SMEs in the manufacturing regime participate in a range of interactional networks that exist as structures that are relied upon to maintain stability and help people make major decisions (Brass et al., 2004; Kilduff & Tsai, 2012). These networks can exert an important influence on views of risk (Helliar et al., 2001), explicitly or covertly (Horlick-Jones & Prades, 2009) and their influencing capability exists irrespective of the level of engagement or awareness of the individual (Vasvári, 2015). Such networks reproduce, reinforce and lock in path dependencies of the existing linear economy production, supply and consumption sociotechnical system (Geels et al., 2018, 2017). However, within the manufacturing regime there will be conflicting and concurring shared understandings, creating dilemmas that allow and reinforce path dependencies and can result in resilience, resistance or opportunities for change, legitimizing or otherwise decisions by actors within the regime (Andrews-Speed, 2016; Billig et al., 1988; Fuenfschilling & Truffer, 2014). As the population associated with the UK manufacturing regime is potentially finite, the strategy adopted for data collection combines forms of purposive, snowballing and opportunistic sampling tactics (Etikan et al., 2016; Lavrakas, 2008; Noy, 2008). Therefore, the analysis in this paper should be viewed as a first stage interpretation based on a convenience sample of individuals.

2.3 Data analysis

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To facilitate data management and analysis, all interview transcripts were incorporated into a computer assisted/aided qualitative data analysis software tool, NVIVO. A 6-step analytical framework was developed built upon a similar approach to that adopted by Willott and Griffin (1999) combining constructivist grounded theory strategies and a CDP approach to enable interpretative analysis of a large quantity of data. The framework is summarized in Table 1 below

Table 1. *Analytical framework.*

Step	Approach	Purpose
Step 1: Initial coding	The development and application of a common coding framework to generate low level "nodes" that categorise features of the discourse irrespective of the type of discourse data collected.	To ensure some level of consistency in data management.
Step 2: Initial interpretation	An analysis of each section of data under a node of interest asking the questions: What is the discourse doing? How is the discourse constructed to make this happen? What resources are available to perform this activity? What is the action orientation of the discourse? What versions of the world are being constructed/ stabilised? Whose interests are being served by the discourse	To provide a descriptive interpretation of what the producer of the discourse was doing in relation to the node and provide insights into how concepts have been constructed.
Step 3: Patterns	A review of the interpretations, identifying recurrent and irregular relationships between the patterns of discourse in relation to the question What is the discourse doing?	To produce a set of patterns of discourse relating to the original node.
Step 4: Theoretical accounts	A review of the patterns of discourse from Step 3 in relation to each of the questions in Step 2, drawing on external sources, identifying consistencies and variations in how the construction of the pattern.	To provide initial theoretical accounts of the patterns of discourse that are potentially culturally, historically, socially or politically specific.
Step 5: Meta-explanation	Application of the patterns of discursive construction to a new node, identification of new patterns or variations.	To determine if patterns in one node provide a "meta-explanation" of the ways another node is discursively constructed.
Step 6: Saturation	The revision, augmentation or discarding of theoretical accounts as appropriate as new nodes are analysed.	Steps 5 and 6 are repeated until no new theoretical accounts are found.

2.3.1 Step 1: Initial coding

The preliminary task of any grounded theory informed discourse analysis research is to code the data as a facilitating mechanism for initial analysis (Potter, 2009). Paragraph by paragraph coding was carried out on all materials analysed to date, with an individual paragraph generally coded at a number of nodes, e.g. risk, SMEs, money, market and customers, subject positioning of others, responsibilities. Such interpretative coding consisted of *imposed etic,* a priori constructs derived from the academic literature and the researchers own knowledge, and *emic* participant codes that became salient during analysis (Morris et al., 1999).

This initial coding process was iterative in that for each interview transcript or piece of published material coded, the initial nodes were refined, added to, made redundant, combined or disaggregated into high level categorisations. Given that the initial nodes were intentionally open to interpretation, different types of discourse data can be coded at the same node.

2.3.2 Step 2: Initial interpretations

In this second step a generic node was selected for analysis, to investigate recurrent or variable discursive patterns in the ways in which risks for SMEs in transitioning to a circular economy were discussed. The node SME was selected as the first node for analysis, on the basis that understanding what meanings are associated with being an SME would potentially relate to how SMEs are positioned in discourse on transitioning to a circular economy and what are understood to be risks for SMEs. 68 sections of interview text were coded at SME in step 1, including sections when it could be inferred respondents were positioning themselves as an SME, for example the utterance "business like us, the size of us" even though the term SME hadn't been used directly. Each section of text was examined in turn and a descriptive interpretation of what the discourse was doing was identified by asking each of the questions defined for Step 2 (see Table 1).

2.3.3 Step 3: Patterns

The interpretative analysis in step 2 indicated that three overarching discourses are used in the construction of risks for SMEs in transitioning to a circular economy:

a discourse of power dynamics in SME-customer relationships;

a discourse of the ideology of the circular economy, and

a discourse of resources in SMEs.

The discourses called upon 26 recurrent discursive patterns, where 10 were interpreted as coherent dominant patterns that called upon 15 subordinate patterns individually or in combination with other subordinate or dominant patterns. This paper focuses on the analysis of the *"if the bigger fish say"* pattern of discourse relating to perceptions of power dynamics in the SME-customer relationship, as interviewees working in businesses (SME), Government (G), business support providers (BSP), academia (A) and business representative bodies (BRB) all engaged in discourse incorporating this discursive pattern in response to a variety of questions. Figure 1 provides a simplified discourse network map for the "if the bigger fish say" pattern of discourse.

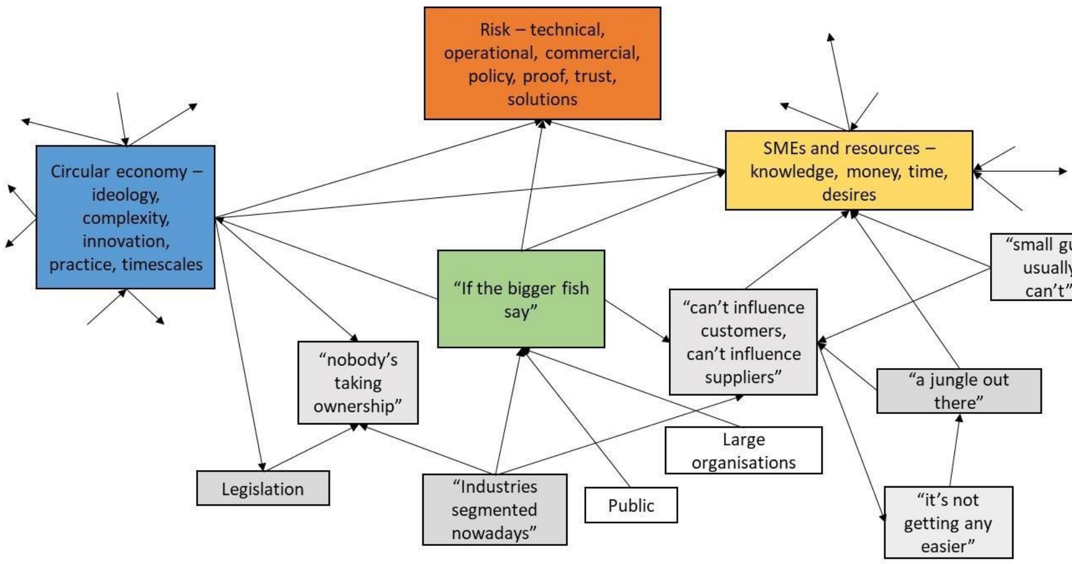

Figure 1. *Network view of the "if the bigger fish say" pattern of discourse (interview*

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2.3.4 Step 4: Theoretical accounts: *"if the bigger fish say"* (E2:SME3)

22 interview extracts (E) that were interpreted as calling upon a "if the bigger fish say" pattern of discourse, coded at Node "SME", were the primary subject of the detailed analysis in this step. Also included were seven business interview extracts from the Node "subject position self" that can be interpreted as calling upon discourses relating to understandings of relationships with customers. Furthermore, 24 interview extracts coded at node "customers and markets" were also brought in and analysed, bringing the total number of extracts informing this analysis to 53. Each extract was analysed in turn with variations and consistencies identified when compared with the next extract. An example analysis is provided below:

Researcher: Is there anything that you, with us having this conversation, that you want to raise that we haven't covered?

Ref	Transcript*
1	SME1: (….) It comes down to, for a business like us, the size of us, we have to think
2	commercially.[I: Um.] And the circular economy really only comes into play if we're driven (0.2) to
3	do that, or if it's something whereby we get a commercial edge, (….)
4	But I think, you know I've never had a conversation with a customer in the last 7 years of (…)
5	existence where they've said (0.4) yeh I'll pay an extra 10 percent if you can show it's ethically
6	sourced, or if, you know, you're not disposing of it, if your waste rates are lower than others, you
7	know.
	<Never> (0.2) have I had anything like that.

** Transcription conventions. (….) transcript deliberately omitted. A word of phrase underlined indicates additional emphasis in speech. [] Indicates an interruption by another person. (1.0) a relative indicator of a length of a pause compared to a usual end of sentence or comma (breath) pause for the speaker. <> slower pace of speaking.>< quickened pace of speaking.? Speech pattern (usually incorporates rising intonation in the sentence) indicates a question*

SME1 positions that SMEs, because of their size, are obligated "have to" to make decisions based on thinking "commercially", i.e. buying, selling and making profit, "It comes down to, for a business like us, the size of us, we have to think commercially."(line 1). Their use of the term "it comes down to" serves to construct thinking commercially as common-sense, rational expected business practices. Given this construction, SME1 can be understood to go on to position that circular economy activity goes against expected practices and is not generally a commercial proposition that SMEs can take voluntarily. This is achieved by SME1 calling upon an account of counter conditions that would over-ride the expected commercially thinking decision-making obligation "really only comes into play if we're driven (0.2) to do that" (line 2). Without external forces obligating them to take action, action on the circular economy is positioned as necessitating the need to fit what is understood of being commercial, helping sell more, reduce costs or make more money "we get a commercial edge"(line 3). By calling upon an account of experience with customers, SME1 can be understood to position that customers are the external force, having the power to obligate action in SMEs, and therefore it is customer responsibility to determine action on the circular economy. In this account emphatic language and the reference to long timeframes is understood to be repeatedly used as a method of signalling the veracity of the statement "I've never had a conversation with a customer in the last 7 years. (….)" (line 4) and "(….) pay an extra 10 percent if you can show it's ethically sourced, or if, you know, you're not disposing of it, if your waste rates are lower than others. (….) <Never> (0.2) have I had anything like that" (lines 5-7).

In this discourse SME1 can be understood to put forward an understanding that the circular economy is associated with managing waste and ethical practices that incur additional costs. SME1 uses this understanding to position that customers prioritise price of service/goods in their interactions with SMEs and are not interested in ethical considerations. Therefore, SME1 can be understood to use this repertoire, centred round the pattern of "if the bigger fish say", to position that customers are responsible for transitioning to a circular economy, as SMEs are powerless to take action due to customer demands for limited costs of goods and the circular economy being an ethical consideration that goes against expected commercial common-sense business practice.

2. Results and discussion

Interviewees developed and used the "if the bigger fish say" pattern by calling upon embedded understandings of a taken for granted, expected hierarchy of power in the manufacturing regime, built upon authoritarian principles where size of the entity relates to the position in the hierarchy. Frequent calls upon terminology related to size and subordinate positions were used to place SMEs low down the hierarchy, with their customers, i.e. bigger businesses, the public sector and the public, up the hierarchy, e.g.:

"the small, the lower down the chain you get" E4:SME3

"But what's interesting then is how the SMEs underneath that then start to respond" E1:BSP2

Combining with terminology of obligation, e.g.:

"(….) the role of most SMEs are to follow. [I: Um] Legislation, and to do things, and to do things that the corp', again unless the public expects things of them, they'll not be doing it." E1:BRB1

"Except if it's the major corporates you know. (….) Erm, the supermarkets will dictate." E3:G1

"And they, they knew what the price was, that they were looking for, and we had to get that price point."E9:SME1

"a lot of SMEs are (0.6) manufacture to print so they're effectively, (0.4) the circular economy (0.4), they have to buy into it because that's, that's what their customers dictate" E1:BSP1

These sentiments positioned asymmetric power relationships between customers and SMEs as a legitimate, commonplace and expected norm in the manufacturing regime, where bigger entities have and exercise power to control and influence the actions of SMEs, restricting their freedom and demanding obedience to their requests, particularly related to costs.

The importance of asymmetric power relations in the manufacturing regime has been the subject of much research, particularly by Actor Network Theory (ANT) informed researchers (Rutherford & Holmes, 2008). *Structural* power asymmetry (the power to influence) is understood to stem from larger entities having control over the key assembly, design rights and end-customer retailing aspects of the supply chain and the scale of accumulated financial assets of the larger entity that has been enhanced by significant restructuring of manufacturing away from vertically integrated structures over the last few decades. Such causal understandings of structural power were made apparent in the extracts through reference to design authority, globalisation of supply chains and

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growing competition and scale of financial resources, e.g.:

"Well, we're not the design authority. The customer is the design authority" E15:SME3

"(….) or any piece of equipment these days has a massive long supply chain. The SMEs have very little chance of influencing that unless they have something really, really clever. And it doesn't cost any extra money. Erm, but gives functionality." E1:G1

"(…) I think that the, you know, the competition from, particularly from Asia [I: um] in manufacturing has, has necessitated for them to operate very, very lean in terms of people and skills [I: um] which makes it even more difficult" E5:BSP1

"(…) we've always been very, very lean burn (…) And it lives or dies on the ability to convince people to buy, to buy products and to continue to buy." E2:SME1

SMEs were positioned as predominantly lacking intellectual property or design rights over products or components, end-customer retail engagement and accumulated financial or skill resources and as such having no structural power. However, such discourse can be understood to neglect the difference between structural power and active power, i.e. the ability or willingness to seek or enact structural power.

An important aspect of active power, aligning with socio-technical regime thinking, is the concept of path dependencies that manifest themselves as control mechanism conditions. A range of theories exist regarding supply chain dependency configurations and the enactment of power therein but, irrespective of configuration, the enactment of bigger customers power in existing arrangements is the most important aspect of operational performance of suppliers and as such is where suppliers focus their attention (Huo et al., 2017). This focus on using resources to maintain existing customer relationships was the basis of the dominant discursive patterns relating to resource, time and money constraints linking with the "if the bigger fish say" pattern of discourse. The nature of the relationship was built predominantly around understandings of a joint dependency configuration. All actors called upon this configuration with its associated understandings of a type of symbiotic relationship having mutual benefit for SMEs and their customers. Benefits to SMEs of this relationship were usually constructed as creating operational and technical stability incorporating costs and income, e.g.

"the business needs a certain level of erm (0.4) (tut) sales in order to keep the lights on. (…) what you didn't want to do is throw away the baby with the bathwater (…) there are some really big desirable customers who could have spent, could have been spending with us 100,000 pounds a year. So you don't want to, you know [I:no] jettison them and annoy them" E1:SME2

with benefits to customers positioned as various combinations of responsiveness, expertise, product performance and economics, e.g.:

"(…) products which we own the rights to ( ) What is a customer looking for there? They're looking for good quality, er competitive pricing, good service and good support and good performance (…) Erm, the other side (…) we make widgets for people, (…) and so what they're usually looking for is quality, erm (2.0) material performance and pricing and speed of response, so you know on time delivery low quality defects etc. etc."E4:SME2

The enactment of power of the customer in this joint dependency arrangement was discursively constructed by all actors as taking both coercive and passive forms, which is not surprising given that enactment of power is spatially and temporally contingent (Sayer, 2004) and can be intentionally activated or have an effect because it is perceived to exist (Ireland & Webb, 2007). The subordinate discourse of the desirability of big customers e.g.,

"(…) if the bigger boys say right then, we expect our suppliers to do this, to do that, to do the other. Erm even if those suppliers think it's a complete waste of time, they'll have to do it because they want the business from the bigger customers" E2:SME3

and the dominant discursive patterns associated with maintaining existing customer relationships, e.g.

"(…) but that's the way sometimes SMEs work, they just, they have to get, they have to fulfil their order commitments (…)" E2:BSP1

are indicators of how passive power influences decisions of SMEs. Both can be understood to relate to *referent* power of big organisations, i.e. the desire to be linked to a big organisation with a high level of esteem to legitimise the credentials of the business (Raven et al., 1998). The work carried out to maintaining existing customer relationships and responding to customer demands is also an indicator that SMEs are complicit in engaging with the perceived *legitimate* power of a big organisation. Such power being socially constituted of understandings of hierarchy, the authority of bigger businesses over SMEs and obligation (Czinkota et al., 2014; Huo et al., 2017). This acknowledgement of the perceived passive power of bigger customers and how it influences the decisions and actions of SMEs goes a long way to explain why the responsibility for transitioning to a circular economy is placed with customers. Such positioning of responsibility was also discursively reinforced by all actors by calling upon understandings of big customers coercive power, e.g.

"(…) but we can actually make somebody else (0.2) do the activity, they'll pass that down the line with their procurement terms." E2:BSP2

and have enacted such power historically, e.g.

"We did have a, a er customer wanting some specific requirements, and it was sort of, to a degree, it was well we'll worry about that later, until that customer rang up and said unless this is resolved in 30 days we're taking all the business away." E2:SME3

but currently do not choose to enact such power in relation to transitioning to a circular economy, e.g.:

"I've never had a conversation with a customer in the last 7 years of (…) existence where they've said (0.4) yeh I'll pay an extra 10 percent if you can show it's ethically sourced, or if, you know, you're not disposing of it, if your waste rates are lower than others, you know." E1:SME1

However, referring back to the identified causal mechanisms of structural power, the analysis to date indicates that there are understandings that perceptions of the *expert or informational* power of a supplier, e.g. knowledge, experience, skills, e.g.

"(...) the customers that are coming to us are coming to us because we've got the right equipment, and the way we operate and accept that they're going to pay a bit more money for that." E12:SME3

and actual expert power, e.g. intellectual property, has the ability to change the power dynamics in SME-customer relationships, e.g:

"But then that's all <around you have to have erm IP in that> (…) And if you can offer something unique and something different to <those big customers> and it means something to them then they become sticky customers because they can't get it elsewhere." E5:SME2

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4.Conclusions

Overall, the analysis of the 53 interview extracts to date calling upon an *"if the bigger fish say"* pattern of discourse indicates that this is a dominant discursive resource used by actors in the manufacturing regime. The pattern is predominantly used to warrant lack of action in SMEs or limit expectations of what can be achieved by SMEs. The arguments build on embedded understandings of a hierarchical regime structure where the structural and active power of larger customers have locked-in SMEs to using all their resources (technical, financial, time, knowledge) in meeting cost obligations to customers to secure business operational stability. However, analysis shows that SMEs, customers and regime network actors are complicit in establishing and maintaining such understandings and joint dependency configurations and using them to validate perceptions of the right solution for transitioning to a circular economy.

Whilst responsibility and accountability for transitioning to a circular economy is oriented to customers (bigger businesses, the public sector and the consumer publics), the gaining of expert power by SMEs to provide solutions for customers that fit within existing cost-centric commercial obligation understandings is routinely presented as the right solution for transition, e.g.:

"...which is longer lasting, typically 2 to 3 times longer lasting than …And it's at a comparative price"E6:SME2

By calling upon this understanding, expert and informational power is positioned as a liberating mechanism for SMEs and as such SMEs are situated as equally, or potentially more, responsible for delivering solutions to transition to a circular economy. It is suggested here that the reliance on expert power as the solution neglects to take account of the influence of instituted structural and active power of customers and the historically and culturally embedded, cost-centric commercial constraints of the existing path dependencies. Failure to address these constraints creates a potential action impasse, as elucidated by one of the interviewees:

"these changes will happen and will cascade down. And timing is all the, they can't make the change until they're told to but they've got to gear up for it and anticipate it." E1:G1

Regarding risk, it is proposed here that voluntarily engaging in activities to support a transition to a circular economy is a risk object for SMEs, where the object at risk is business survival with consequences negatively impacting upon the ability for SMEs to meet their commercial obligations where there is no expert power advantage. However, given the asymmetric power dynamics of the relationship with bigger customers, it is surmised that this is underpinned by an understanding that bigger customers are also risk objects for SMEs. This is on the basis that in responding to circular economy-related demands from customers, SMEs are expected to do so within the constraints of maintaining current cost neutral or reduction expectations of customers, whilst it is understood that circular economy action incurs additional cost:

"(…) yeh I'll pay an extra 10 percent if you can show it's ethically sourced, or if, you know, you're not disposing of it, if your waste rates are lower than others" E1:SME1

The discourse of power in transitioning to a circular economy indicates the existence of a stalemate in the ability to deliver aspirations to transition to a circular economy. We put forward that a causal mechanism of this stalemate is a reliance on expert power of SMEs (and businesses in general) as the solution without changing how customers enact their power in the manufacturing regime. In conclusion, to reduce negative perceptions of risk in transitioning to a circular economy, the discursive evidence points to a necessity to move away from a reliance on expert power of SMEs, to taking action that changes mechanisms that prioritise cost advantage to customers and maintaining the structural and active power of such customers

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An integrated circular business model typology based on consolidated circular economy principles

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Abstract

This paper aims to unify academic understanding of the circular economy principles in one hand and consolidate on the other hand business models configurations built from these principles. More precisely, the paper aims to contribute to the ongoing theoretical discussion on the classification of circular business models by linking systematically circular economy principles with associated business model strategies. By doing so, it opens avenue for future research on the different mechanisms inherent to each circular business models and allows specifying distinctive tensions attached to their development and implementation. Starting from circular economy definitions and its core features, we clarify generic principles associated with the concept, based on existing schools of thought. Taking a micro-level perspective focusing on business model innovation, we highlight recognized definitions on sustainable business models and frame circular business models as a subset of sustainable business models. The analysis shows that there is a gap between the current understanding of CE (definitions and principles) and subsequent circular business model emerging theory. In order to reduce this gap, we formalize a set of guiding principles which bridge general CE theory with circular business models. Seven guiding principles are identified: regenerating loop, narrowing loop, slowing loop, intensifying loop, dematerializing loop, cascading loop and closing loop principles. We also recognize that beyond these guiding principles, circular business models can be classified based on (1) the business model orientation (material – product – service) (2) the focus taken by the business model on the product lifetime phases (pre-use, use, post-use), and lastly (3) its circular value dynamics (retain value, optimize value, recover value). The development of these criteria allow us to build an integrated typology using existing categorization attempts from 19 publications and consolidate circular business models into five distinctive categories. The integrated typology describes five generic circular business models: (1) clean loops business models, (2) short loop business models, (3) access loops business models, (4) cascading loops business models and (5)long loops business models. Each business model is described with a focus on its value proposition and associated business model components (value creation, value delivery, value capture). The outcome of the article (consolidated typology and associated criteria) allows us to consolidate the definition of circular business models as the rationale of how a company creates, deliver, retain, optimize, capture, and recover superior sustainable value by regenerating, closing, narrowing, slowing, intensifying, dematerializing and cascading resource loops within its value network, thus supporting its stakeholders without undermining the functioning of the biosphere or crossing any planetary boundaries. This definition reinforces the links between circular business models and sustainable business models (the former being a subset of the latter, but sharing a similar overall objective) while at the same time characterizing the specific principles guiding the implementation of circular economy at business level.

Keywords: Circular Economy, Business Model, Typology

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1.Introduction

Our current take make waste linear economy is increasing pressure on our ecosystems and accelerates environmental degradation: biodiversity loss, water, air, and soil pollution, resource depletion, and excessive land use (Meadows et al., 2004, Rockström et al., 2009, WBCSD, 2010). When searching for alternatives models, the circular economy concept, while not entirely new, has gained traction at business (EMF, 2012) and policy levels (EC, 2014), for its potential to operationalize the broader concept of sustainable development (Murray and al, 2017). Circular economy can be defined as "one that is restorative by design, and which aims to keep products, components and materials at their highest utility and value, at all times" (Webster, 2015). At its core is the circular (closed) flow of materials and the use of raw materials and energy through multiple phases" (Yuan et al., 2008). The acknowledgment of the limits to planetary resource and energy use, and the importance of viewing the world as a "system" in which pollution and waste are designed out, lay at the foundations of circular economy thinking (Bocken, 2016). This transformational approach requires new interventions at macro-level (cities, regions and nations), meso-level (business networks, industrial parks), and micro-level (individual businesses) (Ghisellini et al. 2016). The implementation of novel business models fitting with circular economy principles is considered a core aspect of this transformation (Brennan et al., 2015). In that respect, this paper focuses on the micro-level and specifically addresses the business model perspective on the transformation to circular economy. "A crucial constituent in the achievement of a circular economy is business model innovation", states De Angelis (2016). The concept of circular economy has become a relevant field of academic research with a steep increase in the number of articles and journals covering this topic during the last decade (Geissdoerfer et al., 2017). However, circular business model literature is only currently emerging as a subset of Sustainable Business Model literature – which focuses on business models "that create, deliver, and capture value for all its stakeholders without depleting the natural, economic, and social capital it relies on" (Breuer and Lüdeke-Freund (2014). A large majority of research is relying on business cases identified from practice to identify definitions, ontologies, building blocks, and configurations supporting business model innovation. But to date, little research has been done to compare and analyse the various approaches developed to create circular business model categorisations, on the exception of Lüdeke-Freund (2018), even though categorisation and clarification is a pre-condition to support knowledge generation. Why do we need to categorize business models? The general idea of business models is intimately linked with notions of taxonomies and 'kinds'. Business models describe typical kinds of organizations and behaviours by firms in such a way that we can label different kinds of behaviour and then classify individual firms accordingly (Baden-Fuller and Morgan (2010). Their classification can be relevant for the possibilities they give us for not only defining but also for exploring characteristic similarities and differences as well as for developing understanding, explanation, prediction and intervention (Baden-Fuller and Morgan, 2010). They can be used to address and help solve lack of knowledge (such as "why" and "how" each model is successful as a business, or why it is profitable). Business Models can also be used as models. They appear as generic in-between kinds-of-descriptions that are neither general theory nor full empirical descriptions. Finally they can also be used as recipes, suggesting why it works, because it embodies the

essential elements and how they are to be combined to make them work. Hence, categorizing circular business models can provide new insights to support research on this emerging trend, which can in turn support companies and entrepreneurs on their transformation to more sustainable and circular value creation processes.

Objective of the paper

This paper aims to unify academic understanding of the circular economy principles in one hand and consolidate on the other hand business models configurations built from these principles. More precisely, this paper aims to contribute to the ongoing theoretical discussion on the classification of circular business models by linking systematically circular economy principles with associated business model strategies. By doing so, it opens avenue for future research on the different mechanisms inherent to each circular business models and allows specifying distinctive tensions attached to their development and implementation. The outcomes facilitate research on CBMI based on a common understanding of CBM underlying principles.

Structure of the paper

First, a review of circular economy definitions and circular economy principles from existing literature is performed to help developing a robust framework of circular principles. These principles allow delineating which business models can be considered circular. Second, a review of the main tenets of business model research and in particular sustainable business model innovation in the context of circular economy is performed. Third, by analysing existing categorisations attempts developed in peer-reviewed and practitioner-oriented publications, the paper proposes a consolidated categorisation alternative that directly links circular economy principles with their inherent business model declinations. Results are discussed and synthetized in the final section. The findings can support future research on CBM but can also be considered useful for practitioners when positioning their value proposition with regards to the circular economy construct. Figure 1 below summarizes the overall structure of the paper.

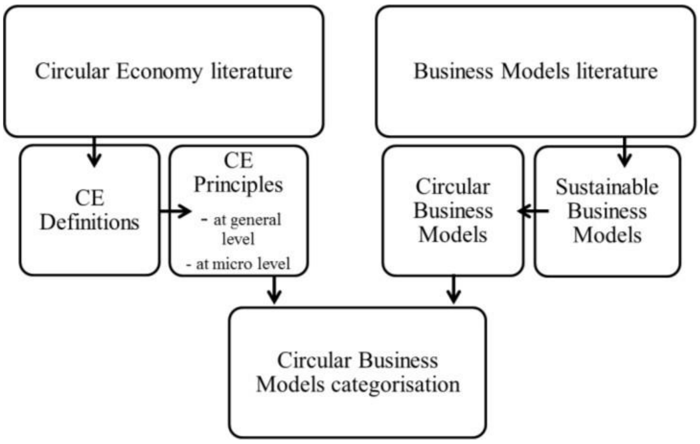

Figure 1: Overview of general paper approach

2.Underlying concepts

Circular economy: definitions and principles

This section synthetizes the insights from systematic literature reviews from Ghisellini et al. (2016) whose purpose is to grasp the main circular economy features and Kirchherr et al. (2017) whose purpose is to create transparency regarding the current understandings of the circular economy concept through the analysis of 114 circular economy definitions. It clarifies the central tenets of circular economy as an academic construct.

Circular economy definitions

If the concept of circular economy is reaching a certain momentum - illustrated by the rising number of academic and practitioner publications (see Kirchherr et al., 2017, Ghisellini et al. 2016, for systematic literature reviews)

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- it however remains blurry in its exact framing (Lieder and Rashid, 2016), certainly because, as an academic construct, it remains "a young field" (Murray et al., 2017). To date, the number of definitions among practitioners and academics exceeds 100 attempts and no consensus is being reached as "there is no single group with the undisputed authority to define what [CE] means exactly" (Gladek, 2017). The conceptualization of circular economy can be addressed through its scope of analysis, its aims and its supporting principles. The review of existing definitions shows a diversity of focus and a strong lack of harmonization (Kirchherr et al., 2017). Indeed, the core concepts depicted in the existing understanding of the CE construct vary in their unit of analysis, whether it is at meta-level (global economy, territory, region), meso-level (industrial park) or micro-level (using a single company as the unit) making it challenging to develop a proper focus. When analysing the content of 114 definitions, Kirchherr et al. (2017) point out that the definitions content has evolved over time. Starting from a focus on the 3R framework (reduce - reuse - recycle), the framing of the concept extended to a systems perspective - circular economy being

understood as a "system that is designed to be restorative and regenerative" (EMF, 2012). If it is commonly understood that circular economy supports sustainable development goals, definitions of the concept however do not systematically link circular economy with the three dimensions of sustainability (environmental quality, economic prosperity and social equity) - the social dimensions is often left behind (Moreau et al., 2017) and the intergenerational dimension of sustainability also lacking. Table 1 provides a set of various definitions: the currently most used in the literature (EMF, 2012) the official EU definition (EC, 2015) and the integrative attempt from Kirchherr et al. (2017).

Table 1: Selected Circular economy definitions

Author	Definition
Ellen MacArthur Foundation (2012)	Circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models.
Preston (2012)	Circular economy is an approach that would transform the function of resources in the economy. Waste from factories would become a valuable input to another process –and products could be repaired, reused or upgraded instead of thrown away.
European Commission (2015)	The circular economy is an economy where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized.
Kirchherr et al. (2017)	A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-

industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations.

Based on their analysis, Kirchherr et al. (2017) argue that to be integrative, a proper definition of circular economy should include the following dimensions: A clear connection to the three sustainability dimensions as the end goal (1); a systems perspective through a multi-level focus (micro-meso-macro) (2); the waste hierarchy and the R's strategies (Reduce, reuse, recycle) as guiding frameworks (3).

Circular economy principles

As perceived in the multiple definitions of the concept, circular economy can be envisioned through different perspectives. Stahel (2010) argues that the circular economy should be considered as a framework. Den Hollander (2017) argues that Circular economy should be considered as an "ideal state" and is therefore guided by normative principles. As a generic notion, the circular economy draws on several more specific approaches that gravitate around a set of basic principles. Circular Economy as a meta concept is thought to be derived from different schools of thought (EMF, 2012): Cradle to Cradle (McDonough and Braungart, 2002), Performance Economy (Stahel, 2010), Regenerative Design (Lyle, 1994), Industrial Ecology (Ayres, 1994), Biomimicry (Benyus, 2002), and the Blue Economy (Pauli, 2010).

These schools of thoughts are directly linked to the core elements of the definition of circular economy and are complementary to each other (Lewandowski, 2015). Industrial ecology focuses on the transition from open to closed cycles of materials and energy to achieve less wasteful industrial processes (Frosch, 1992, Erkman, 1997) Biomimicry is an approach to innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested patterns and strategies. The goal is to create products, processes, and policies—new ways of living—that are well-adapted to life on earth over the long haul (Benyus, 2002). Cradle-to-cradle is a framework for designing products and industrial processes that turn materials into nutrients by enabling their perpetual flow within one of two distinct metabolisms: the biological metabolism and the technical metabolism. Cradle-to-cradle design supports the creation of wholly beneficial industrial systems driven by the synergistic pursuit of positive economic, environmental and social goals (Braungart and al., 2007). The performance economy (Stahel, 2010) is characterized by a focus on utilization and performance in use, not manufacturing, an optimization of existing stock, and the selling of goods as services, where manufacturers retain ownership of goods and embodied resources, and internalize the cost of risk and of waste. The Blue economy (Pauli, 2010) is creating value from 'using the resources available in cascading systems, (…) the waste of one product becomes the input to create a new cash flow'. Regenerative Design (Lyle, 1994) is a system of technologies and strategies, based on an understanding of the inner working of ecosystems that generates designs to regenerate rather than deplete underlying life support systems and resources within socio-ecological wholes. If some of these approaches have made important sustainability science contributions, the connection to the concept of CE is unclear and difficult to comprehend (Korhonen, 2018). Table 2 below provides an overview of the various principles drawn from related circular economy schools of thought and consolidates them into eight circular economy principles.

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Table 2: Consolidation of CE principles based on CE schools of thought

<table>
<tr><th></th><th>SCOPE</th><th colspan="2">Energy</th><th colspan="5">Resource/Material</th><th colspan="3">Process</th><th colspan="3">Organisation</th><th colspan="2">System</th><th colspan="2">Context</th></tr>
<tr><td rowspan="6">SCHOOLS OF THOUGHT</td><td>Biomimicry (Benyus, 1997)</td><td></td><td></td><td>Use life-friendly chemistry</td><td colspan="2">Be resource efficient</td><td colspan="2"></td><td colspan="3"></td><td>Evolve to survive</td><td>Adapt to changing conditions</td><td>Integrate development with growth</td><td colspan="2"></td><td colspan="2">Be locally attuned and responsive</td></tr>
<tr><td>Cradle to cradle (Braungart and McDonough 2002)</td><td>Use current solar income</td><td></td><td>Waste is food (biocycle)</td><td colspan="4">Waste is food (technical cycle)</td><td colspan="3"></td><td>Celebrate diversity</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Performance economy (Stahel 2010)</td><td></td><td></td><td></td><td colspan="2">Optimisation of existing stock</td><td colspan="2">Extend product life</td><td></td><td>Focus on performance</td><td>Sell goods as services</td><td colspan="3"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Industrial ecology (Erkman, 2001)</td><td>Energy must rely less on fossil hydrocarbon</td><td></td><td></td><td>Waste must be valorized</td><td>Loss caused by dispersion must be minimized</td><td colspan="2">Economy must be Dematerialised</td><td colspan="3"></td><td colspan="3"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Blue economy (Pauli, 2012)</td><td></td><td></td><td></td><td colspan="2">Be efficient (substitute something with nothing)</td><td colspan="2"></td><td>Be profitable (optimize & generate multiple cash flows)</td><td colspan="2">Be innovative (create change, seize opportunities)</td><td colspan="3">Be abundant (satisfy all basic needs)</td><td colspan="2">Be systemic (mimic nature)</td><td colspan="2">Be local (use what you have)</td></tr>
<tr><td>Regenerative design (Lyle, 1994)</td><td></td><td>Use Information to Replace Power</td><td>Letting nature do the work</td><td colspan="2">Shape form to guide flow</td><td>Shape the form to manifest the process</td><td>Manage Storage</td><td colspan="3"></td><td>Seeking optimum levels for multiple functions</td><td>Provide Multiple Pathways</td><td></td><td>Aggregating not isolating</td><td>Seek common solutions to disparate problems</td><td>Consider nature as both model and context</td><td>Matching technology to need</td></tr>
<tr><td></td><td>circular principle</td><td colspan="2">Use Renewable energy principle</td><td>Use bio materials principle</td><td colspan="4">Resource-efficiency principles</td><td>Cascading principle</td><td colspan="2">Performance principle</td><td colspan="3">Resilience principle</td><td colspan="2">Systems thinking principle</td><td colspan="2">Act local principle</td></tr>
</table>

Principles can be classified based on the levels of intervention, from a micro level (energy and resources) to meso (process, organization) and macro level (system and context), see Figure 1 below.

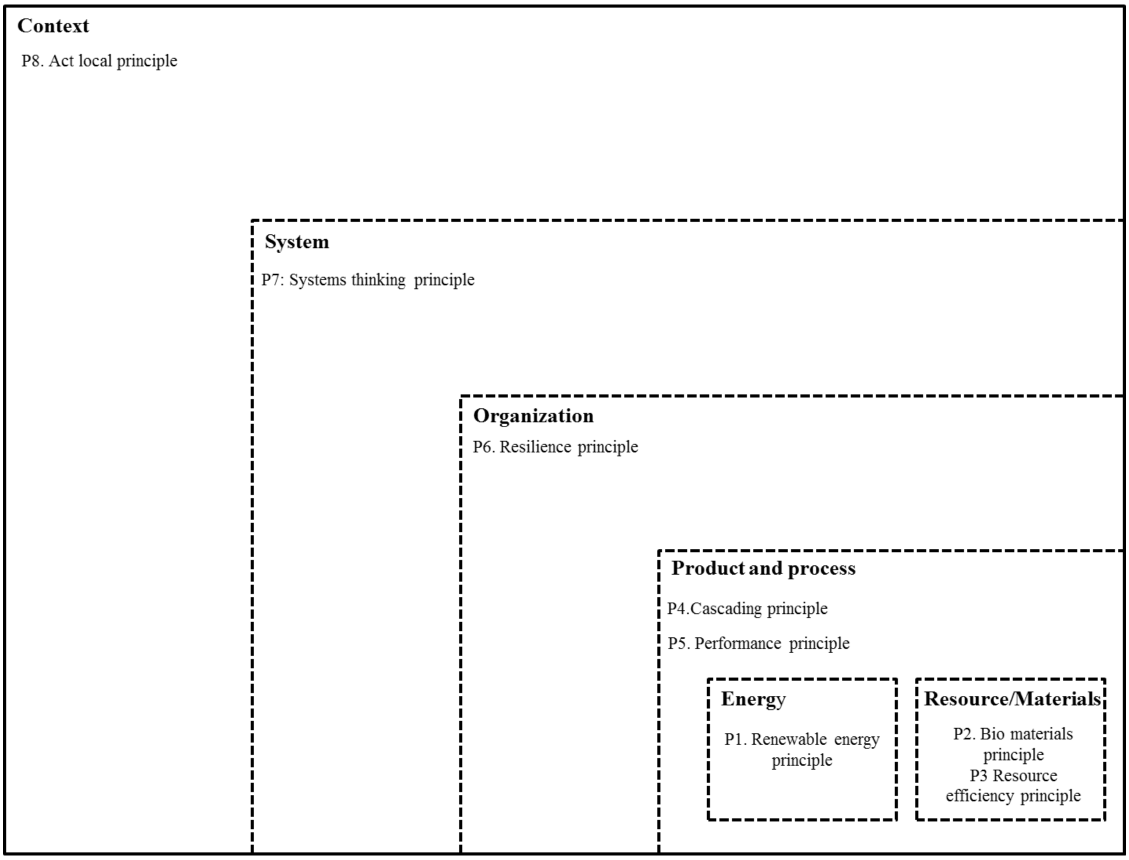

Figure 2: Circular economy principles

At energy level, the core principle is the use of renewable energy (McDonough and Braungart, 2002). At resource level, the two principles are use of bio-materials (Benyus, 2002; McDonough and Braungart, 2002) and seeking resource efficiency (McDonough and Braungart, 2002; Stahel, 2010; Lyle, 1994; Benyus, 2002; Pauli, 2010) in which the 3Rs framework is embedded. At product and process level, the focus rests on cascading (Pauli, 2010) and performance principles (Stahel, 2010). Resilience thinking principle and Systems thinking principle constitute the core principles at organization and system level respectively (Lyle, 1994, Pauli 2010, Benyus 2002, McDonough and Braungart, 2002). At context level, the act local principle drives (Benyus, 2002, Pauli, 2010, Lyle, 1994).

These eight principles remain rather broad and are often constituted of several sub-principles. For instance, according to Benyus (2002) in Biomimicry, the “Resource efficient” principle includes using multifunctional design (meet multiple needs with one elegant solution); using low energy processes (minimize energy consumption by reducing requisite temperatures, pressures, and/or time for reactions); recycling all materials (keep all materials in a closed loop) and fitting form to function (select shape or pattern based on need). In the context of business model innovation, the first five principles constitute the starting point for circular business models principles development as outlined in section 3.

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2.2Business models

This section introduces business model as a research construct with a focus on its definitions and principles.

Business model definitions and principles

The business model construct "draws from and integrates a variety of academic and functional disciplines" (Chesbrough & Rosenbloom, 2002,). A business model describes the rationale of how an organization creates, delivers and captures value (Osterwalder and Pigneur, 2010). The literature offers different angles on the business model concept. It is defined as the organizational and financial "architecture" on how a firm does business, a "recipe" on how resources and capabilities are translated into economic value (Teece, 2010), a crossroad between competences and consumer needs (Sabatier, Mangematin, Rouselle, 2010). Osterwalder and Pigneur (2010) describe a business model as a series of interconnected elements: the value proposition (product/service offering), customer segments, customer relationships, activities, resources, partners, distribution channels, cost structure, and revenue model. These elements can be consolidated into three main categories: the value proposition, the value creation and delivery system and the value capture system (Richardson, 2008). Taking an activity-based approach, the business model synthetizes the 'What' (selection of activities), the 'How' (activity system structure) and the 'Who' (actors performing the activities) (Zott and Amit, 2010).

Business model literature has been focusing on three streams of research: Technological, organizational, and strategic level (Wirtz, 2011). As a result of the internet booming in the early 90s, a large set of literature has focused on the adoption of new technologies forced firms to rethink their profits earning strategies (Timmers, 1998). At organizational level, business model has been addressed as a strategic management tool to improve a company's value chain (Tikkanen et al., 2005) and organizational efficiency. At strategic level, the business model construct has been perceived as a tool to develop competitive advantage (Chesbrough, 2010).

Sustainable business models

The business model perspective is particularly relevant in the context of sustainability (Schaltegger et al., 2016) because it highlights the value creation logic of an organization and its effects and helps transcend narrow for-profit and profit-maximizing models. Schaltegger et al. (2016) define business model for sustainability (or sustainable business model – SBM) as one "that helps describing, analyzing, managing, and communicating (i) a company's sustainable value proposition to its customers, and all other stakeholders, (ii) how it creates and delivers this value,

(iii) and how it captures economic value while maintaining or regenerating natural, social, and economic capital beyond its organizational boundaries." SBM can be conceptualized in various ways: as a narrative of sustainability practices; a description of features, attributes, and/or characteristics; a list of necessary and sufficient conditions; a representation of business processes; a firm-level description; a systems-level description; or some combinations of these (Stubbs and Cocklin, 2008).

What are the normative requirements of a sustainable business model? Boons and Lüdeke-Freund (2013), based on a literature review, developed basic normative requirements for the different elements of business models: The value proposition must provide both ecological or social and economic value through offering products and services, the business infrastructure must be rooted in principles of sustainable supply chain management, the customer interface must enable close relationships with customers and other stakeholders to be able to take responsibility for production and consumption systems and the financial model should distribute economic costs and benefits equitably among actors involved. Upward and Jones (2016), taking a "strongly sustainable" perspective, articulates four propositions: A strongly sustainable business model creates ecological, social and economic value throughout its value network, which implies an extended understanding of the value that is proposed, delivered and finally created.

Circular Business Models

This section provides an overview of circular business models definitions, distinct features and introduces specific variables aiming at supporting a classification approach. Circular Business Models are considered a subset of the broader group of sustainable business models (Bocken et al. 2014). Several definitions of circular business models can be found in the recent literature (Roos, 2014, Mentink, 2014, Linder and Williander 2015, Den Hollander and Bakker, Nußholz (2017) Smith-Gillespie, 2017), but currently no consensus has emerged on a generic definition. Mentink (2014) defines circular business model as "the rationale of how an organization creates, delivers and captures value with and within closed material loops" while Linder and Williander (2015) define a circular business model as "a business model in which the conceptual logic for value creation is based on utilizing the economic value retained in products after use in the production of new offerings". Surprisingly, definitions generally take an economic focus when looking at the value creation delivery and process, omitting the sustainability goals generally found in sustainable business models definitions (Boons and Lüdeke-Freund, 2013, Schaltegger et al., 2012, Stubbs and Cocklin, 2008, Evans et al., 2014). Some definitions offer descriptions on the strategies behind the value creation process, with a clear focus on resource flows and the goal to maintain products and materials at their highest value for a longer time while other remain at a very conceptual level, framing the rationale within closed material loops. Only Geissdoerfer et al. (2018) definition directly links CBM to SBM. Table 3 below provides an overview of recent definitions found in the literature.

Table 3: Selected circular business models definitions

Source	Definition	Aim	Value creation focus	Strategy/ principles
Roos (2014)	A circular value chain business model (or green business model) is one in which all intermediary outputs that have no further use in the value creating activities of the firms are monetised in the form of either cost reductions or revenue streams.	Monetarisation of resources through Cost reduction and extra revenue stream.	Economic value of underused assets	Not mentioned
Mentink (2014)	A circular business model is the rationale of how an organization creates, delivers and captures value with and within closed material loops	Not mentioned	Generic economic value	Focus on closed material loops
Linder and Williande r (2015)	A business model in which the conceptual logic for value creation is based on utilising the economic value retained in products after use in the production of a new offerings. Thus, a circular business model implies a return flow to the producer from users, though there can be intermediaries between the two parties [...and] always involves recycling, remanufacturing, reuse or of their sibling activities (e.g., refurbishment, renovation, repair).	Not mentioned.	Economic value of product after use.	Focus on Reverse flow of resources Principles: recycling, remanufacturing, reuse or of their sibling activities (e.g., refurbishment, renovation, repair)."

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Den Hollander and Bakker (2016)	"A circular business model describes how an organization creates, delivers, and captures value in a circular economic system, whereby the business rationale needs to be designed in such a way that it prevents, postpones or reverses obsolescence, minimizes leakage and favours the use of 'presources' over the use of resources in the process of creating, delivering and capturing value.	that it prevents, postpones or reverses obsolescence, minimizes leakage and favours the use of 'presources'	Economic value	No principles integrated
Nußholz (2017)	A circular business model is how a company creates, captures, and delivers value with the value creation logic designed to improve resource efficiency through contributing to extending useful life of products and parts (e.g., through long-life design, repair and remanufacturing) and closing material loops.	Improve resource efficiency	Generic economic value	Extending useful life of products and parts and closing material loops
Smith-Gillespie (2017)	A circular economy business model is one which creates, delivers, and captures value in a manner that is compatible with and enables regeneration of finite natural resources, and keeps products, components and materials at their highest value and utility within a relevant system boundary.	Enabling regeneration of finite natural resources	Generic value	Keeping products, components and materials at their highest value and utility
Geissdoerfer et al. (2018)	CBMs can be defined as SBMs specifically aiming at solutions for the Circular Economy through a circular value chain and stakeholder incentive alignment.	Solutions for circular economy	Not mentioned	Circular value chain, stakeholder incentive alignment

The weakness and inconsistency in describing the concept may add to the difficulty to clarify which business models are considered circular or not. When defining a circular business model, aims, principles and strategies should be described and aligned with the definition of circular economy. Despite this weakness, literature on circular economy
is growing and addresses the circular business model topic from multiple perspectives (Lewandowski, 2015). Focus can be on adoption factors (Laubscher and Marinelli, 2014), design and managerial tools (Van Renswoude et al. 2015, Joustra, 2013), or evaluation models (Scheepens et al, 2016). Several papers focus on categorizing circular business models, which will be extensively reviewed in section 4 of this paper).

How do CBM differ from traditional business models? Adopting a circular economy strategy requires several organizational and strategic shifts. Looking at the business model architecture including value creation, value proposition, value delivery and value capture, the following changes are required, according to Mentink (2014) cited in Lewandowski (2015). In the Value Creation (1) component, products have to be made in specific processes, with recycled materials and specific resources, which may require not only specific capabilities but also creating reverse logistics systems and maintaining relationships with other companies and customers to assure closing of material loops (Wrinkler, 2011). In the Value proposition (2) component :products should become fully reused or recycled, or firms should turn towards product-service system (PSS) and sell performance related to serviced products activities, processes, resources and capabilities. In the Value delivery (3) component: selling "circular" products or services may require prior changes of customer habits or, if this is not possible, even changes of customers. Last, in the Value capture (4) component: a shift would be required to sell product-based services charged according to their use. These general normative requirements however lack the precision needed to tackle business model innovation in each distinctive circular business model.

Characteristics supporting CBM categorizations

In this paper we argue that circular business models should primarily be characterized based on their adoption of circular economy principles (see next section). However other approaches may be relevant to differentiate existing circular business models strategies. Circular business models can be characterized taking a product lifetime perspective (Den Hollander, 2017). Product lifetime can be defined as the timespan between the moment a product starts being used after manufacture, ending at the moment the product becomes obsolete beyond recovery at product level. Using this perspective, circular business models can be classified according to their position on three distinct phases: creating value prior to the use of the product (focus on the quality of materials to be used in the manufacturing process), during the use of the product (in one or several use cycles if the product is reused) or creating value following the use of the product (by recovering materials for future purposes).

The position of these business models according to the product lifetime also has consequences on the value dynamics being unfolded. During the pre-use and the use phases, circular business models primarily aim to retain value: in the pre-use phase, by designing long lasting products or products in which materials can easily be recovered and reprocessed for future use; in the use phase by offering services aiming at prolonging the use lifetime of the products. During the use phase, circular business models may also focus on strategies aiming at optimizing value, by maximizing the usage of the product (i.e. through sharing practices). Finally, during the post-use phase,

circular business models may focus on Recovering value – that is developing operations to reverse material obsolescence. Circular business models can also be classified based on the importance stressed on materials, products, or services associated to the product.

3.From general principles to circular business models guiding principles

The section introduces an integrated set of circular economy principles at micro level which support the classification of circular business models. Several authors (Stahel 2016, Bocken, 2016, Geissdoerfer et al, 2018) have focused on translating the generic circular economy principles into more applicable principles guiding circular business model innovation. At the core of a CBM is the aim to create value from the (re) circulation of product and material flows. Researchers in circular economy often describe this goal taking a loop perspective – that is a structure, series, or process, the end of which is connected to the beginning (Oxford definition) – to clarify how value is created, as illustrated by the now famous Butterfly diagram (EMF, 2013). Stahel (2016) distinguishes two fundamentally different types of loops: reuse of goods, and recycling of materials. “Circular economy business models fall in two groups: those that foster reuse and extend service life through repair, remanufacture, upgrades and retrofits; and those that turn old goods into as new resources by recycling the materials”.

Building from Stahel (2016) and Braungart (2002), Bocken’s (2016) classification approach distinguishes circular resource loops based on the speed of circulation of material flows, the closing features of material flows and the

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volume of materials flows circulating:

(1)Slowing resource loops: Through the design of long-life goods and product-life extension (i.e. service loops to extend a product's life, for instance through repair, remanufacturing), the utilization period of products is extended and/or intensified, resulting in a slowdown of the flow of resources.

Closing resource loops: Through recycling, the loop between post-use and production is closed, resulting in a circular flow of resources.

Resource efficiency or narrowing resource loops, aimed at using fewer resources per product.

Geissdoerfer et al (2018) extended this approach further and emphasized the importance of two additional loops:

Intensifying loops: strategies leading to a more intense use phase.

Dematerializing loops: the substitution of product utility by service and software solutions.

These five loops however fail to incorporate two main circular economy principles as recognized in the CE literature: the use of bio-based, biodegradable, compostable, or renewable resources to regenerate natural capitals -

the regenerating loops – and the – (7) cascading loops – which maximizes resource effectiveness by using biomass in products that create the most economic value over multiple lifetimes. These two core characteristics are therefore integrated in our conceptual approach to support the categorization of circular business models. Table 3 below summarizes the distinctive characteristics of circular economy principles as opposed to linear economy.

Table 4: linear vs circular economy principles

Resource flow characteristics	Linear Economy	Circular Economy		
Type of resource	Finite resources	Renewable resources	▶	**Regenerating loop**
Resource intensity	Resource intensive	Resource efficient	▶	**Narrowing loop**
Speed of circulation	Fast speed	Slow speed	▶	**Slowing loop**
Usage intensity	Low intensity	High intensity	▶	**Intensifying loop**
Intangible resource intensity	Materialized	Dematerialized	▶	**Dematerializing loop**
Number of lifecycles	Single lifecycle	Multiple lifecycles	▶	**Cascading loop**
Direction	Linear	Circular	▶	**Closed loop**

These seven loops constitute the guiding principles from which circular business models can be designed. Taking this into account the next section provides an overview of existing categorization of circular business models in the literature – using the seven principles listed above as a one of the classifying criteria.

4. An integrated classification of circular business models

The recognition of similarities and differences between business models and the development of classes of business models are central to business model research (Lambert, 2006). Indeed "Theory cannot explain much if it is based on an inadequate system of classification" (Bailey, 1994). In order to theorize further the concept of CBM, it is necessary to order or classify the objects within the concept as a good classification scheme forms the foundation of theory development. Classifications can be seen as a bridge between a simple concept and a theory. They help to organize abstract, complex concepts (Neuman, 2003) through the ordering of objects into groups or classes on the basis of their similarity (Bailey, 1994).

One distinction in classification schemes is between typologies and taxonomies, although many researchers when developing classifications use the terms interchangeably. In typologies, the researcher conceptualizes the different

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types that are relevant to the research. These types form the cells of the classification scheme and each cell is labelled (named). Based on the scheme, the researcher identifies cases that possess the characteristics deemed essential to fit the cells, in a deductive approach. Typologies allow simplifying complex concepts by classifying objects according to a few criteria at a time. They provide a solid foundation for both theorizing and empirical research' (Bailey, 1994). Taxonomies, in contrast to typologies, are generated from inductive research and derived empirically (Sokal and Sneath, 1963). Unlike typologies whereby the categories are derived conceptually, taxonomic categories are derived through cluster analysis (Lambert, 2006). Taxonomy can be used to refer to a process and the end result. To date, research into business models has been conceptual and any empirical research has been deductive (Lambert, 2006), therefore classifications have been mainly typologies. Following a deductive approach, the section below describes the methodology developed to support an integrated typology.

4.1 Methodology

Literature review

This paper uses a systematic review approach to formalize a typology of circular business models. The following academic databases were used for the literature search: Scopus, science direct. Searching keywords included variations (e.g. plural, singular) on terms such as circular business model, circular economy business models, sustainable business model, green business model. The resulting literature, as well as its references, was scanned for explicit mention of categorizations and classification of cases studies and examples of circular business models. Due to the limited amount of results from academic publications, a review of secondary literature was also conducted. Reports including categorization attempts and case studies on sustainable and circular business models were selected. In total, 19 references were selected for review as shown in table 5.

Defining characteristics for integrated typology

When developing our typology, we focused particularly on trying to achieve the following characteristics, based on typology characteristics defined by Weill (2005):

The typology should be intuitively sensible: it should capture the common intuitive sense of what a business model means by grouping together businesses that seem similar in their business approach, and separating businesses that seem different.

Similarities and differences should not just be at a superficial level: the typology should group together businesses at the deeper level of how their activities create value. The names of different categories should also be self-explanatory.

The typology should be comprehensive: it should provide a systematic way of classifying all businesses adopting circular economy principles

The typology should be clearly defined. That is, it should define systematic rules for determining the business model(s) of a given company in a way that does not depend on highly subjective judgment.

The typology should be conceptually elegant. The concepts should be simple, and as self-evidently complete as possible.

Criteria identification for classification:

The circular business models categories should be classified according to the Circular Economy principles as previously defined.

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o 7 principles are used to define the business model, taking a resource loop perspective: regenerating loop, slowing loop, narrowing loop, intensifying loop, dematerializing loop, cascading loop and closing loop - based on Stahel (2016) , Braungart (2002), Bocken (2016) and Geissdoerfer et al (2018).
The circular business models should be classified according to their position on the lifetime of the product (pre-use, use, post-use).
The circular business models should be classified according to their material-product-service orientation.
The circular business models should be classified according to the value dynamics associated with their (retain value, optimize value, recover value).

Integration of existing categories into a systematic classification

First, each categorization attempt is scanned and described based on the criteria selected. Second, individual classes that are redundant are grouped. Third, distinctive classes are reorganized based on the CE principles, the position on the product use cycle (pre-use, use, post-use) and the orientation of the business model (material, product or service focus). Finally, similar classes are clustered into integrated categories. The results describe each circular business model, highlighting aims, supporting principles, position in the product-use cycle, orientation and value creation mechanisms.

4.2 Analysis of existing classifications

19 categorizations from academic and practitioners were reviewed (see table 5) resulting in a database of 97 entries (see annex 1 for complete database). Academic papers included Tukker (2004), Braungart et al. (2007), Bakker et al (2014), Bocken et al. (2014), Mentink (2014), Albino and Fraccascia (2015), Bocken et al. (2016) , Planing (2015), Lüdeke-Freund et al.(2018). The practitioner literature included Pauli (2010), Beltramello et al. (2013), Accenture (2014), Bisgaard et al. (2012), Clinton and Whisnant (2014) Nguyen et al (2014), Van Renswoude (2015), Kiørboe et al (2015), Wrap (2016).

Table 5: Overview of papers classifying circular business models

Author	Publication name	Circular business model	Sustainable business model (including circular principles)	Novel business models (including circular principles)	Green business model (including circular principles)	Specific business model focus (Pss, IE, C2C)	number of BM categories	number of categories fitting with CE principles (sub categories)
Bocken et al. (2014)	*A literature and practice review to develop sustainable business model archetypes*		x				8	3 (22)
Bocken et al. (2016)	*Product design and business model strategies for a circular economy*	x					4	4
Albino and Fraccascia (2015)	*The industrial symbiosis approach: A classification of business models.*					x	6	6
Tukker (2004)	*Eight types of product-service system: Eight ways to sustainability?*					x	8	4
Bakker et al (2014)	*Products that last: Product design for circular business models.*	x					5	5
Planing (2015)	*Business model innovation in a circular economy reasons for non-acceptance of circular business models.*	x					9	9
Mentink (2014)	*Circular Business Model Innovation: A Process Framework and a Tool for Business Model Innovation in a Circular Economy*	x					8	7
Braungart et al., 2007	*Cradle-to-cradle design: Creating healthy emissions – A strategy for eco-effective product and system design.*					x	1	1
Lüdeke-Freund et al.,2018	*A Review and Typology of Circular Economy Business Model Patterns*	x					6	6

Author	Publication name	Circular business model	Sustainable business model (including circular principles)	Innovative business models (including circular principles)	Green business model (including circular principles)	Specific business model focus (Pss, IE, C2C)	number of BM categories	number of categories fitting with CE principles (sub categories)
Accenture (2014)	*Circular advantage. Innovative business models and technologies to create value in a world without limits to growth*	x					5	5
Van Renswoude (2015)	*Circular Business Models Part 2: Overview and examples*	x					6	6 (19)
Kiørboe et al (2015)	*Moving towards a circular economy—Successful Nordic business models.*	x					6	6
Wrap (2016)	*Innovative Business Model Map*			x			10	10
Beltramello et al. (2013)	*Why New Business Models Matter for Green Growth.*				x		9	3
Bisgaard et al. (2012)	*Green Business Model Innovation - Conceptualisation, Next Practice and Policy. Nordic Innovation, Oslo.*				x		2 (9)	2 (9)
Clinton and Whisnant (2014)	*Model Behavior – 20 Business Model Innovations for Sustainability.*		x				20	6
Pauli (2010)	*The Blue Economy: 10 Years, 100 Innovations, 100 Million Jobs*					x	1	1
Nguyen et al (2014)	*Remaking the industrial economy*	x					4	4
Smith-Gillespie (2017)	*Defining the Concept of Circular Economy Business Model*	x					7	7

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The analysis of the papers reflects different categorization methodologies, various scopes and focuses, which leads to lack of clarity and omissions as described below.

Categorization methodologies

Methodologies used to support the categorization of business models are diverse and not always consistent, when even clarified. When described, approaches follow a deductive or an inductive approach. Some categories start from a conceptualization process and are then illustrated through business cases fitting within the defined concept. Alternatively, some approaches start from a pre-identification of business cases which are then later clustered into distinctive categories (Albino and Fraccascia, 2015). Often the criteria for classification are not described (Accenture, 2014, Bisgaard et al., 2012), which lead to think the categorization was not objectively defined.

Different scopes

Some categorizations focus only on a subset of circular strategies (industrial ecology business models for Albino and Fraccascia, 2015, Product-Service Systems for Tukker, 2004), while others only categorize main approaches, while failing to define subcategories (i.e. Beltramello et al., 2013). Categorizations attempts in green/sustainable business models publications generally integrate business models relying on circular economy principles, but they often are diluted in other categories. For instance, in Bocken, (2014), business models addressing Circular economy principles can be found in 3 different sustainable business models archetypes – create value from waste; deliver functionality rather than ownership substitute with renewables and natural processes).

Integration vs multiplication

Some of the business model categories incorporate two or more potentially very distinct models, such as the business model 'Product Life Extension' including both remanufacturing and repair (Accenture, 2014) for which value creation processes and outcomes are very distinctive . At the other end of the spectrum, some categorizations attempts multiply the approaches resulting in a numerous typology (i.e. nineteen distinct business models identified in Renswoude et al., 2015)

Lack of clarity

Some categorization s mix production method (e.g. '3D printing') with business models (Van Renswoude, 2015); or use an enabling mechanism which doesn't necessarily characterize an entire business model (e.g. 'take back management'). Different labels are also used for the same concepts (e.g. "performance", "access", "products as a service" business models).

Omissions

Depending on the starting point, several categorization attempts seem to omit relevant CE principles (e.g. use of renewable energy or biomaterials) as a starting point, therefore missing a variety of business models fitting in the circular economy framework.

4.3Results: an integrated typology

Based on the initial analysis of the paper, the clustering and integration resulted in the following typology presented in table 6. The typology aims to provide an integrated classification based on existing typologies attempts found in the literature, using a new set of criteria supporting the classification (CE principles, position in the product use lifetime, business model orientation, value dynamics) allowing to merge categories sharing similar characteristics and consequently separate other categories in distinctive categories. Five generic circular business models can be delineated as a result from the classification: “Clean loop”, “Short loop”, “Access loop”, “Cascading loop and “Long loop” business models. The subsequent paragraphs provide a brief outline of these six business models, details characteristics and differences, while highlighting features of their value creation, delivery and capture mechanisms. As a result of the classification and integration, several business models also have sub-categories. The explanation for this level-2 classification is detailed in dedicated tables below.

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Circular business model	Description	Associated categories in literature	CE principles							Position in the product use cycle	Business model orientation	Value dynamics
			(1) Regenerating loop	(2) Narrowing loop	(3) Slowing loop	(4) Intensifying	(5) Dematerializing loop	(6) Cascading loop	(7) Closing loop			
(1) Clean loop	Business model is designed around fully renewable, recyclable or biodegradable inputs	Circular supplies (Accenture, 2014), Substitute with renewables and natural processes (bocken, 2014), Product design (Kiørboe et al., 2015), cradle to cradle (Braungart et al., 2007), Pure circles (Renswoude et al. 2015) power of pure circles (Nguyen, Stuchtey, and Zils, 2014), Circular sourcing (Smith-Gillespie, 2017), organic feedstock (Lüdeke-Freund et al.,2018)	•							Pre-use	Material	Retain value
(2) Short loop	Business model is designed around products manufactured for extended life time and aditional value is created through services supporting the maintenance of the product for the same customer (Repair, upgrade), or different customer (reuse, remanufacture)	Product life extension (Accenture, 2014), Classic long life model (Bocken, 2016), extended product value (Bocken, 2016), Repair, reuse (Kiørboe et al., 2015), short cycles (Renswoude et al. 2015), Maintenance/ Repair/Redistribution/Upgrading/Remanufacturing (Mentink, 2014), hybrid model (Bakker et al., 2014), gap exploiter model (Bakker et al.,2014), Incentivised return & re-use (Wrap, 2016), Power of the inner circle (Nguyen, Stuchtey, and Zils, 2014), Recondition (Smith-Gillespie,2017), Repair & maintenance/Reuse & redistribution /Refurbishment & remanufacturing (Lüdeke-Freund et al.,2018)		•	•					Use, Post-use	Product (Service)	Retain value
(3) Access loop	Business model is designed around offering access to a solution through leasing/hiring/renting products without change of ownership or through a platform allowing maximisation of utilisation.	Access and performance model (Bocken, 2016), Product as a service (Accenture, 2014, Clinton and Whisnant, 2014), sharing platforms (Accenture, 2014), Online waste exchange platform (Albino and Fraccascia, 2015), Functional sales and management services models (Beltramello et al., 2013), Incentive models (Bisgaard et al., 2012), Deliver functionality, rather than ownership (Bocken, 2014), Service and function based models (Kiørboe et al., 2015), Collaborative consumption (Kiørboe et al., 2015), Access model / Collaborative Consumption (Planing, 2015), Performance model/Products as Services / Result-based models (planing, 2015) Pay per service unit/Product lease/Product renting or sharing/Functional result (Tukker, 2004), Dematerialized services (Renswoude et al. 2015), Performance model (Bakker et al.,2014), Product-service systems (Wrap, 2016), Dematerialized services (Wrap, 2016), Hire and leasing models (Wrap, 2016), Collaborative consumption (Wrap, 2016), Performance (Smith-Gillespie (2017), Access (Smith-Gillespie (2017)				•	•			Use	Service	Optimize value
(4) Cascading loop	Business model is designed to diversify the use of materials and products to create value from coproducts in multiple value chains within and between industries	Waste exchange (Albino and Fraccascia, 2015), Coproduct generation (Albino and Fraccascia, 2015), Industrial symbiosis (Beltramello et al., 2013, Bocken,2016), life-cycle models (Bisgaard et al., 2012), rematerialization (Clinton and Whisnant, 2014), Multiple cash flows/multiple revenues (Pauli, 2010), cascades (Renswoude et al.2015), coproduct recovery (Smith-Gillespie, 2017), cascading and repurposing (Lüdeke-Freund et al.,2018), Organic feedstock (Lüdeke-Freund et al.,2018)						•		Post-use	Material (Product)	recover value
(5) Long loop	Business model is designed based on recovering already used-resources in order to extend the value of resource through recycling	Create value from waste (bocken,2014), Extending resource value (Bocken, 2016), Resource Recovery (Accenture, 2014), IS-based business oriented to product generation (Albino and Fraccascia, 2015), Waste regeneration systems (Beltramello et al., 2013), life-cycle models (Bisgaard et al., 2012), Closed-loop productions (Clinton and Whisnant, 2014), Recycling and waste management (Kiørboe et al., 2015), Recycling (Mentink, 2014), resource recovery (Smith-Gillespie, 2017), Recycling (Lüdeke-Freund et al.,2018)							•	Post-use	Material (Product)	recover value

Table 6: Circular business model typology

Clean loops business models

Clean loops business models are built on "Circular supplies" (Accenture, 2014), "Pure circles" (Renswoude et al., 2015) "Circular sourcing" (Smith-Gillespie, 2017), "Substitute with renewable and natural processes" (Bocken, 2014) categories found in the literature. In these generic circular business models, value creation is designed around the use of materials that are renewable, recyclable or biodegradable. Clean loops business models focus on the regenerative feature of the circular economy definition (EMF, 2012) and adopt the regenerating loop principle. By using renewable and recyclable inputs, the business model rationale enables materials to be returned to either the technical or biological cycle and enables 100% closed material loops (Braungart, 2002). The central circular value dynamic is to retain value of the materials used while maintaining the quality of the materials for many consecutive cycles (Nguyen, Stuchtey and Zils, 2017). The value creation mechanism is based on the integration of materials in products during the manufacturing/production stage, prior to the use phase. The value proposition in these business models focus on the benefits attached to a product made of renewable/recyclable materials, which may appeal to target customers, whether they are quality-conscious customers or green customers. Value delivery is generally not differentiated on these business models (use of traditional distribution systems). Value capture is generally associated to additional product revenues (price premiums) associated to intrinsic quality of the product (i.e.: organic, fully recyclable and recycled). Table 7 below provides an overview of the level 2 categories in the clean loop business model.

Table 7: Clean loop business models

CLEAN LOOP (1) Business model is designed around fully renewable, recyclable or biodegradable inputs,		**CE principle: Regenerating** **Position in life cycle: Pre-use** **Value dynamics: Retain** **BM orientation: Material**
Category (level 2)	**Description**	**Associated categories in literature**
1.1 Biosourced loop	Value creation through the use of renewable materials	Circular supplies (Accenture, 2014), Substitute with renewables and natural processes (bocken, 2014), Product design (Kiørboe et al., 2015) Cradle to cradle (Braungart et al., 2007) Pure circles (Renswoude et al. 2015) Power of pure circles (Nguyen, Stuchtey, and Zils, 2014), Circular sourcing (Smith-Gillespie, 2017), organic feedstock (Lüdeke-Freund et al.,2018)
1.3 Recylable loop	Value creation through the use of fully recyclable materials	Circular supplies (Accenture, 2014), Product design (Kiørboe et al., 2015), Cradle to cradle (Braungart et al., 2007), Pure circles (Renswoude et al. 2015), Power of pure circles (Nguyen, Stuchtey, and Zils, 2014), Circular sourcing (Smith-Gillespie, 2017)
1.2 Recycled loop	Value creation through the use of recycled materials	Circular supplies (Accenture, 2014), Product design (Kiørboe et al., 2015),Cradle to cradle (Braungart et al., 2007)Pure circles (Renswoude et al. 2015), Power of pure circles (Nguyen, Stuchtey, and Zils, 2014), Circular sourcing (Smith-Gillespie, 2017)

Short loops business models

Short loops business models are built on, "Product life extension" (Accenture, 2014), "Extended product value" (Bocken, 2016), "Repair, reuse (Kiørboe et al., 2015)", "short cycles" (Renswoude et al. 2015), "Maintenance/ Repair/Redistribution/Upgrading/Remanufacturing" (Mentink, 2014), "hybrid model" (Bakker et al., 2014), "Gap exploiter model" (Bakker et al.,2014), "Incentivised return & re-use" (Wrap, 2016), "Power of the inner circle"
(Nguyen, Stuchtey, and Zils, 2014), "Recondition" (Smith-Gillespie,2017), "Classic long life model" (Bocken, 2016), "Repair & maintenance/Reuse & redistribution /Refurbishment & remanufacturing" (Lüdeke-Freund et

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al.,2018) categories found in the literature. In these generic circular business models, value creation is designed around products manufactured for an extended life time and additional value is created through services supporting the maintenance of the product for the same customer (Repair, upgrade), or different customers (reuse, remanufacture). As the circulation of resources remain in the form of a product in Short loop business models, the loop between product provider and users is considered "short" as opposed to Long loop business models (see below) in which the loop is focusing on materials which inherently extends the length of the loop, including the participation of additional agents (waste processing and material manufacturers) in the cycle. Short loops business models adopt two Circular Economy principles: the narrowing loop principle and the slowing loop principle (Bocken, 2016). On one hand, by producing long-lasting products these business models eliminate the need to extract additional virgin resources in order to replace existing products, thus reducing the amount of resources in circulation. On the other hand, by providing a full range of services aiming at extending the useful lifetime of products, they reduce the speed of circulation of materials and products. The central circular value dynamic is to retain value in the existing products for as long as possible during the use phase as well as in the post-use phase when recovering products to be remanufactured/refurbished. The value creation mechanism in place is based on designing long lasting products and on the other hand on using skills and competences supporting the maintenance, repair or upgrading of products for existing customers, or refurbishing/remanufacturing capabilities to recirculate products to new customers. The value proposition in the short loop business models focus on one hand on offering customers long lasting quality products, and on the other hand on a set of solutions supporting the sustainable functioning of these products by offering services such as repair, maintenance, upgradability. Value delivery presupposes on one hand the introduction of take-back systems in order to link existing customers to repair centers back and forth, as well as dedicated distribution centers delivering reused/remanufactured/refurbished products. Value capture is generally associated to payments related to the service offered (repair/upgrade), or to the costs savings associated to resource savings when refurbishing/remanufacturing new products using recovered products/components. Table 8 below provides an overview of the level 2 categories in the Short loop business model.

Table 8: Short loop business models

SHORT LOOP (2) Business model is designed around products manufactured for extended life time and additional value is created through services supporting the maintenance of the product for the same customer (Repair, upgrade), or different customer (reuse, remanufacture)		**CE principle: Slowing, narrowing** **Position in life cycle: use, post-use** **Value dynamics: Retain** **BM Orientation: Product (service)**
Category (level 2)	**Description**	**Associated categories in literature**
2.1 long life	Value creation based on manufacturing high-quality, long-lasting products	Classic long life model (Bocken, 2016), Long life (Wrap, 2016)
2.2 Extended life (single user)	Value creation based on additional services extending the life of the product for the same user (maintenance, repair, upgrade)	Product life extension (Accenture, 2014), Repair/maintain (Planning, 2015), Recondition (Smith-Gillespie,2017), Repair & maintenance (Lüdeke-Freund et al.,2018)
2.3 Extended life (multiple users)	Value creation based on processes extending the life of the product for other users (reuse, remanufacture, refurbishing)	Extended product value (Bocken, 2016), reuse/refurbish/ redistribute/ Next- Life Sales (Planing, 2015),Incentivised return & re-use (Wrap, 2016), Remake (Smith-Gillespie, 2017), Reuse & redistribution (Lüdeke-Freund et al.,2018), Refurbishment & remanufacturing (Lüdeke-Freund et al.,2018)

Access loops business models

Access loops business models are built on "Access and performance model" (Bocken, 2016), "Product as a service" (Accenture, 2014, Clinton and Whisnant, 2014), "sharing platforms (Accenture, 2014)", "Functional sales and management services models" (Beltramello et al., 2013), "Incentive models" (Bisgaard et al., 2012), "Deliver functionality, rather than ownership" (Bocken, 2014), "Service and function based models" (Kiørboe et al., 2015), "collaborative consumption" (Kiørboe et al., 2015), "Access model / Collaborative Consumption" (Planing, 2015), "Performance model/Products as Services / Result-based models" (planing, 2015) "Pay per service unit/Product lease/Product renting or sharing/Functional result" (Tukker, 2004), "Dematerialized services" (Renswoude et al. 2015), "Performance model" (Bakker et al.,2014), "Product-service systems" (Wrap, 2016), "Dematerialized services" (Wrap, 2016), "Hire and leasing models" (Wrap, 2016), "collaborative consumption" (Wrap, 2016), "Performance" (Smith-Gillespie (2017), "Access" (Smith-Gillespie (2017) categories found in the literature. In these generic circular business models, value creation is designed around offering access to a solution through leasing/hiring/renting products without necessarily a change of ownership (Product-Service systems), or through a platform allowing multiple users to maximize the rate of utilization of products (Platform business models). Access loops business models adopt two circular economy principles, the dematerializing loop and the intensifying loop (Geissdoerfer et al (2018). On one hand by focusing on the functional results rather than on the product associated to the solution, these business models dematerialize value creation through a focus on servitization. On the other hand, product use is intensified through an optimization of the value delivery, allowing multiple users to access one single product, therefore maximizing the use rate of the products. The central circular value dynamic is to optimize value during the use phase. The value proposition in these business models focus on providing the functions and benefits of the product instead of the physical product itself (Beltramello et al., 2013). The users' needs are met without them having to own physical products. On the other hand, these business models facilitate the sharing of overcapacity or underutilization, increasing productivity and user value (Accenture, 2014) Value delivery is performed through long-term contractual agreement between provider and customer (PSS) or through a market- place based approach allowing the sharing of goods and services (Platform). Value capture is generally associated to payments for function or results or payments per unit of service. In this approach, product longevity, reusability, and sharing are perceived are perceived as drivers of revenues and reduced costs (Accenture, 2014). Other value capture mechanisms include service fee or membership fees to access the associated platforms. Table 9 below provides an overview of the level 2 categories in the Access loop business model.

Table 9: Access loop business models

ACCESS LOOP (3)		
Business model is designed around offering access to a solution through leasing/hiring/renting products without necessarily a change of ownership or through a platform allowing maximisation of utilisation.		**CE Principle: Dematerialising loop, intensifying loop** **Position in life cycle: Use** **Value dynamics: Optimize** **BM orientation: Service**
Category (level 2)	**Description**	**Associated categories in literature**
3.1PSS	Value creation through delivering a function/result rather than a product. Products are used by one or many customers through a lease or pay-for-use or functional results value capture mechanisms	Product as a service (Accenture, 2014, Clinton and Whisnant, 2014), Access and performance model (Bocken, 2016), Service and function based models (Kiørboe et al., 2015), Performance model/Products as Services / Result-based models (planing, 2015) Pay per service unit/ Product lease /Product renting or sharing /Functional result (Tukker, 2004) Performance model (Bakker et al., 2014), PSS (Wrap, 2016), Hire and leasing models (Wrap, 2016), Performance (Smith-Gillespie (2017), Access (Smith-Gillespie, 2017)
3.2 Platform	Value creation through a platform connecting product users (B2B or B2C), providing access to a product/service which allows to maximise product utilisation	Sharing platform (Accenture, 2014), Shared resources (Clinton and Whisnant, 2014), Collaborative consumption (Kiørboe et al., 2015, Wrap, 2016), Access model / Collaborative Consumption (Planing, 2015), Dematerialized services (Renswoude et al. 2015), Access model (Bakker et al., 2014), Asset management (Wrap, 2016)

Cascading loops business models

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Cascading loops business models are built on “Waste exchange” (Albino and Fraccascia, 2015), “Coproduct generation” (Albino and Fraccascia, 2015), “Industrial symbiosis” (Beltramello et al., 2013, Bocken,2016), “life- cycle models” (Bisgaard et al., 2012), “Rematerialization” (Clinton and Whisnant, 2014), “Multiple cash flows/multiple revenues” (Pauli, 2010), “Cascades” (Renswoude et al.2015), “Coproduct recovery” (Smith-Gillespie, 2017), “Cascading and repurposing” (Lüdeke-Freund et al.,2018), “Organic feedstock” (Lüdeke-Freund et al.,2018) categories found in the literature. In these generic circular business models, value creation is designed around a multiplication of uses of materials to create new value from coproducts in multiple value chains within and between industries. Cascading loops business models adopt the cascading loop principle. In these process-orientated solutions, waste outputs from one process are turned into feedstock for another process or product line (Bocken et al., 2016). The central circular value dynamic is to recover value. The value creation mechanism is based on recovering materials and energy from internal processes either to be reused internally or to be exchanged for the benefits of another industry. Cascading loops business models are inspired by the ecological principle called “waste is food” by Braungart and al. (2007). In order to be implemented, skills and competences are required to reprocess waste and recover value from energy and material flows. The value proposition in these business models focus on providing used resources to feed in another industry process or new products made from used resources to final consumers. Value proposition is considered multiple as with one set of resources, multiple customers from different industries and sectors can benefit from the solutions developed. Value delivery focuses on one hand on providing used materials, components or waste to be reprocessed by a third party, and on the other hand on taking back used components or materials to feed into own processes. Value capture is generally associated to additional revenues generated from the sale of materials or energy to be reused in other industries processes, as well as cost reductions from reusing materials and energy. Using the resources available in cascading systems, the waste of one product becomes the input to create a new cash flow (Pauli, 2010). Table 10 below provides an overview of the level 2 categories in the Cascading loop business model

Table 10: Cascading loop business models

CASCADING LOOP (4)		
Business model is designed to diversify the use of materials to create new value from coproducts in multiple value chains within and between industries		**CE principle: Cascading** **Position in life cycle: Post-use** **Value dynamics: recovery** **BM orientation: Material (product)**
Category (level 2)	**Description**	**Associated categories in literature**
4.1 Waste exchange	Value creation is based on reusing Waste produced by a given production process as input by another production process internally or externally, allowing for multiple value creation from the same material source	Waste exchange (Albino and Fraccascia, 2015) Waste regeneration systems (Beltramello et al., 2013) Energy recovery (Planing, 2015, Mentink, 2014)
4.2 Waste as coproduct	Value creation is based on a business enlargement strategy since new products are added to the ones currently produced by the company.	Coproduct generation (Albino and Fraccascia, 2015), Multiple cash flows/multiple revenues (Pauli, 2010), coproduct recovery (Smith-Gillespie, 2017), Cascading and repurposing (Lüdeke-Freund et al.,2018)

Long loops business models

Long loops business models are built on “Create value from waste” (bocken,2014), “Extending resource value” (Bocken, 2016), “Resource Recovery” (Accenture, 2014), “IS-based business oriented to product generation” (Albino and Fraccascia, 2015), “Waste regeneration systems” (Beltramello et al., 2013), “life-cycle models” (Bisgaard et al., 2012), “Closed-loop productions” (Clinton and Whisnant, 2014), “Recycling and waste management" (Kiørboe et al., 2015), Recycling (Mentink, 2014), "Resource recovery" (Smith-Gillespie, 2017), "Recycling" (Lüdeke-Freund et al.,2018) categories. In these generic circular business models, value creation is designed around recovering already used-resources from discarded products in order to extend the value of resource through recycling. Long loops business models adopt the closing loop principle (Bocken, 2016). Materials are recovered to be reprocessed into new components or products. Long loop business models can provide downcycling solutions or upcycling solutions. In the latter, materials are reprocessed into higher-quality and value products, while downcycling generally decreased the embodied value of the recovered material (McDonough and Braungart, 2013). The central circular value dynamic is to recover value in the post-use phase, focusing on the recovered materials. The value proposition in these business models focuses on offering new products based on recycled waste /recovered materials, or developing higher-level competences to support customers in handling and processing recovered waste. The value creation mechanism is based on adopting waste handling and processing capabilities as well as reverse supply chains logistics allowing to take back used products or materials and recycle them for another lifecycle. Value delivery in long loop business models is focusing on connecting suppliers of discarded material (companies or consumers) with new customers Value capture is generally associated to the generation of additional product revenues. Table 11 below provides an overview of the level 2 categories in the Long loop business model

Table 11: Long loop business models

LONG LOOP (5) Business model is designed based on recovering already used-resources from existing products in order to extend the value of resource through recycling		**CE principle: Closing** **Position in the life cycle: Post-use** **Value dynamics: Recovery** **BM orientation: Material (Product)**
Category (level 2)	**Description**	**Associated categories in literature**
5.1 Resource Recovery	Value creation through recovering resources from discarded products, and integrating these inputs into new products	Create value from waste (bocken,2014), Extending resource value (Bocken, 2016), Resource Recovery (Accenture, 2014), IS-based business oriented to product generation (Albino and Fraccascia, 2015), Waste regeneration systems (Beltramello et al., 2013), life-cycle models (Bisgaard et al., 2012), Closed-loop productions (Clinton and Whisnant, 2014), Recycling and waste management (Kiørboe et al., 2015), Recycling (Mentink, 2014), resource recovery (Smith-Gillespie (2017), Recycling (Lüdeke-Freund et al.,2018)

5.Discussion and conclusions

In this article, we aimed to develop an integrated typology of circular business models. Starting from circular economy definitions and its core features, we clarified generic principles associated with the concept, based on existing schools of thought. Taking a micro-level perspective focusing on business model innovation, we highlighted recognized definitions on sustainable business models and framed circular business models as a subset of sustainable business models. The analysis showed that there is a gap between the current understanding of CE (definitions and principles) and subsequent circular business model emerging theory. In order to reduce this gap, we formalize a set of guiding principles which bridge general CE theory with circular business models. Seven guiding principles are identified: regenerating loop, narrowing loop, slowing loop, intensifying loop, dematerializing loop, cascading loop and closing loop principles. We also recognize that beyond these guiding principles, circular business models can be classified based on (1) the business model orientation (material – product – service) (2) the focus taken by the business model on the product lifetime phases (pre-use, use, post-

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use), and lastly (3) its circular value dynamics (retain value, optimize value, recover value). The development of these criteria allow us to build an integrated typology using existing categorization attempts from 19 publications and consolidate circular business models into five distinctive categories. The integrated typology describes five generic circular business models: (1) clean loops business models, (2) short loop business models, (3) access loops business models, (4) cascading loops business models and (5)long loops business models. Each business model is described with a focus on its value proposition and associated business model components (value creation, value delivery, value capture).

Theoretical implications

Circular economy can be considered as an ideal state, and by extension, it is acknowledged that 100% circular business models do not exist (yet) (Renswoude et al, 2015). The classification exercise done in this integrated typology allows however to serve as a more robust foundation to explore further the specific mechanisms taking place in circular business models, in relation to value creation. Second, the outcome of the article (consolidated typology and associated criteria) allows us to consolidate the definition of circular business models as the rationale of how a company creates, deliver, retain, optimize, capture, and recover superior sustainable value by regenerating, closing, narrowing, slowing, intensifying, dematerializing and cascading resource loops within its value network, thus supporting its stakeholders without undermining the functioning of the biosphere or crossing any planetary boundaries. This definition reinforces the links between circular business models and sustainable business models (the former being a subset of the latter, but sharing a similar overall objective) while at the same time characterizing the specific principles guiding the implementation of circular economy at business level.

Managerial implications

The typology developed in this paper provides a basis for comparison and communication that can support companies when trying to position themselves in the circular business models map. In that sense, it provides companies a starting point to explore new avenues and promising implementations of innovative sustainable business models.

Limitations

The deductive approach used in consolidating the typology is not without flaws. As new business models in the circular economy constantly surface, a more iterative approach would be needed to revisit this typology on a regular basis. Business models examples can support the conceptualization of circular economy: describing good circular economy implementation examples can help sharpen the understanding of the circular economy concept both among scholars and practitioners. At the same time a strong concept of circular economy is needed to clarify what is a CE business model. This tension between practical examples on one hand and general concepts on the other hand is at the core of theory forming, which is still emerging in the context of circular business models. Thus, more extensive work is needed to refine the defined concepts and consolidate knowledge. Examples depicted in the existing literature also show that a single company can develop its business model using several principles and value creation mechanisms, thus developing hybrid combinations (i.e: clean loop+access loop business model) which raises the complexity of identifying specific characteristics associated with each category of the typology.

Research avenues

The classification presented above supports a better understanding of circular business models based on a clear recognition of associated principles, position in the life cycle and material -product-service orientation. However, the current classification does not yet inform on the mechanisms supporting a successful implementation of these circular business models. It would become relevant in future research to validate if specific distinctive mechanisms occur in each business model category when addressing for instance the interactions between the focal company and its customers – which distinctive mechanisms support customer value creation in the different circular business models categories? , the type of competences needed to support a circular business model – Are there specific circular dynamic capabilities supporting the implementation of circular business models? Or, as the circular economy is systemic by definition, the role of business networks in creating, delivering and capturing sustainable value – how can circular value networks be created and managed to sustain circular business models

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Design New Products with Natural Stone Waste

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Abstract

Major events in the history of human civilization are often labelled with terms such as Stone Age, Iron Age, Bronze Age, Industrial Revolution, or Information Age. Today, the new era of Re-use, Reduce and Recycling has already started. Those events, so remarkable for the human being, have a common characteristic: the discovery, extraction, processing and use of natural materials from the Earth, many of them giving name to its era. The extractive industry plays a crucial role in the current development of our society, providing key raw materials for the industry. However, the negative impact associated with this activity is evident. The growing demand for non- renewable resources, because of the continuous growth of the world's population, makes it urgent to look for other alternatives, to guarantee the sustainability of the planet. Knowing that the mining industry and particularly in natural stone quarries, the percentage of unused stone material (waste) can reach 70% of the total volume of extracted stone, laying down that new uses for the waste materials is a priority which promotes the new paradigm of circular economy and sustainable development. This work explores the possibility of reuse waste generated by the stone extraction industry, through the production of composite materials formulated with stone particles of different grain size joined together by an epoxy resin. The stones used in this study were obtained from the residues from two quarries of natural stone, a marble quarry located in the south of Portugal and a schist quarry in the north of Portugal. The physical-mechanical properties of the stones used were already known and are published in the Catalogue of Portuguese Ornamental Stones. Subsequently, the physical-mechanical properties of the original rocks were compared with those determined in the produced samples. The manufacture of samples made it possible to evaluate the behaviour of the components of the mixture from the aesthetical point of view, but also in terms of their main features, through testing; the physical and mechanical properties were determined. The results led us to conclude that the composite with the most promising properties does not present enough mechanical resistance for structural applications, like some ornamental rocks do; however, it represents a great opportunity to design decorative artefacts for different industrial sectors. Considering the results obtained, a lamp and a decorative panel were designed and manufactured using shale and marble, taking advantage of the observed contrast between dark and opaque shale grains with translucent and light grains of marble.

Keywords: Waste, Natural Stone, Composite, Design, Epoxy Resin

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1.Introduction

Considering the occurrence location of a mineral resource (beneath the ground surface or in deep underground) and its length, in depth, it can be mined with one (or both) of these two mining techniques: underground mining (mines) and open pit mining (quarries). In this simplistic perspective, a quarry is usually an open pit excavation where the extraction focus is the stone itself; it can be removed in the form of single blocks, gravel or sand, depending on the occurrence type and the end use (Schrenk, 2016).

The production and waste amount from the mining activity depends on many factors, including: the nature of the resource, the technological development of mining, the environmental concerns, etc.. For example, in Australia, solid waste from the mining industry makes up 80% of all solid waste generated by that country. per year (Boger, 1998). In South Africa this figure is 72.3% (Maboeta and van Rensburg, 2003) and in China is 70% (Liao et al., 2007). In the case of natural stone quarries, the volume of natural stone waste can reach 75% of the total mined volume. The different heterogeneities in rocky massifs (lithological, chromatic, textural, physical-mechanical, etc.) generate large amount stone fragments and blocks that do not meet the market requirements. The extraction process and subsequent treatments also contribute to an increase in the amount of waste produced (University of Tennessee, 2011).

The vast majority of existing products and that exist nowadays depend upon the raw materials provided by the extractive industries. Common everyday objects such as mobile phones, televisions and computers are made up of dozens of different minerals (Larsen et al., 2018). Although these industries have contributed to humankind evolution, the amount of waste generated in their production is a serious environmental threat to the future of our planet (K-Jr et al., 2016).

Waste causes economic problems (spoilage without economic recovery) and its ongoing deposition in the soil may lead to potential environmental troubles (soil and underground water contaminations due to the presence of polluting chemical elements in the stones). The need to remove the topsoil to reach the mineral resources can sometimes cause changes on landscape and natural vegetation, affecting their aesthetic value, constraining local agriculture and creating limitations on local populations (Castro et al., 2012). Even after rehabilitation of the mined areas, local fauna and floras sometimes experience recovery delays which are aggravated by the natural erosion processes both by the wind and rain, causing a greater impact of the problems above mentioned (Zoran et al., 2010).

Through a design-centric approach, the practical use of waste generated by the mining industry in the manufacture of new products can help to reduce their amount. In this way, the mined and unused mineral resources can be valued by the companies, thus contributing not only to a better economic use of the resources, but also to the reduction of the environmental impact of this industrial waste.

1.1 Reutilization of waste

The classic mining activity can be subdivided into several steps: mining – extraction of any underground mineral resource; mineral processing – physical and / or chemical separation of the ore from the rock that surrounds it; mining-metallurgical extraction – involves fusion of the ore leaving as residue the surrounding rock. Any of the mentioned processes (mining, separation and/or extraction and concentration), or even the removal of the topsoil, always involves the production of waste (Lottermoser, 2010; Dhar and Thakur, 1996).

Natural stone mining begins with the extraction of stone blocks using a variety of equipment and technology, such as diamond wire or sawing machines, which cut this natural resource cleanly and consistently. Usually, a large volume block is first dismantled from the rock massif. It is then cut into smaller blocks (up to 24 tons) to enable loading and transport with a loader to the truck and finally transported to the processing plant. Some quarries are located in remote areas, far from the processing plants; transportation on roads, which sometimes present degraded pavement (due to the permanent circulation of trucks with heavy loads of natural stone) can be an additional problem when using this natural resource. In the processing plant, the blocks are first cut into rough slabs, with the intended thickness. The seen face and the rear face are then treated to give them the desired surface finish. Lastly, the rough slabs are cut to the required plane dimensions for the final product (Bedrosians, 2017) (Figure 1).

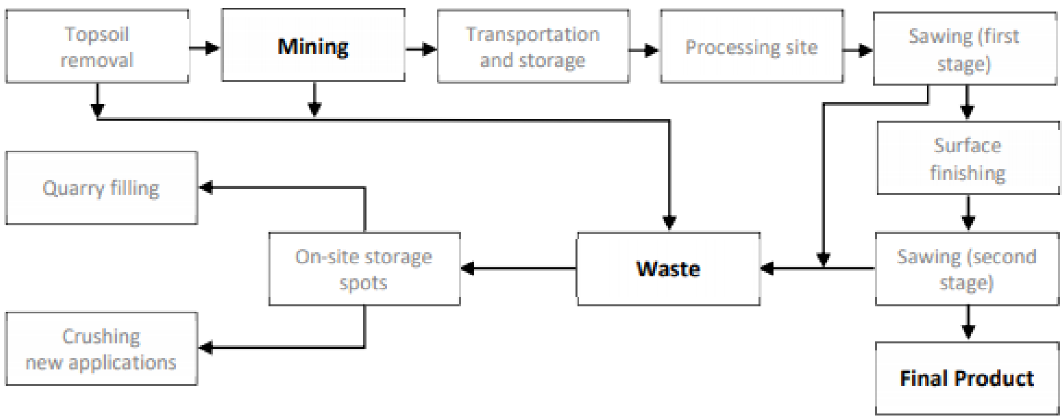

Figure 1. *Diagram of the natural stone mining process, adapted from (*University of Tennessee, 2008).

Besides the adoption of management and planning strategies for mines and mining sites, aiming at waste reduction, the introduction of this waste into the production and manufacture of conventional products (well-defined markets) is already a reality. For instance, the mortar used for the production of some concrete types, in addition to the aggregates, it also includes slag resulting from the smelting of metal ores. This slag is also employed in asphalt and in rock wool used for thermal and acoustic insulation.

There are still other productions where waste from mining rocky massifs is used, such as the production of engineered stone. This manufacture involves moulding a mixture of natural stone waste with mortar, or with epoxy resin, resulting in products with texture similar to some natural stones (Ukcsa, 2017). There are also examples of cut-to-size products for vanity and kitchens and bathrooms tops and products for exterior draining pavements (Figure 2). Natural stone waste is also being used for the production of 3D printing filaments, together with resins, as binder (Cosentino, 2017; TH-PAV, 2016; Saunders, 2017). In all of the above examples, natural stone residues have to undergo a pre-comminution operation to reduce their particle size to the desired calibre.

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The obtained aggregates (or powders) are then mixed with different types of binders, which harden and give form to the mixture after moulding.

Figure 2. *Examples of the production of a draining pavement Marmo Drain (left) (TH-PAV, 2016) and a fountain made of engineered stone (right) (Ukcsa, 2017).*

These examples demonstrate that there is a great opportunity for the use of quarry waste.

2.Methods

Experimental work has arisen from the interest of finding a way to utilize an extremely abundant waste, resulting from mining a natural resource, whose is scarcely economically valued. Next, it is described the process of obtaining an engineered stone composite material, consisting of a low particle size stone aggregate which was mixed with a resin, as binder. Samples consisting of test specimens were fabricated and used to carry out the physical and mechanical characterization of the composite.

Although the specimens' mechanical properties depend, in part, on the lithology and original characteristics of the used stone, when the particle size is reduced to 2 mm or less and a binder is added, the resulting engineered stone has its own properties, dependent on that mixture. At this stage, the lithology of the stones used will have a major influence on aspects such as the colour and texture of the engineered stone, which are important aspects to explore in order to bring design value to the project.

A low viscosity epoxy resin was used as a binder, Biresin CR83, with a mass ratio of 100 to 30 of the respective catalyst (Biresin CR83-6). It was intended to maximize the percentage of waste used, however its increase led to greater difficulty in processing the mixing and aggregation of the composite. The amounts of resin used varied according to what was intended to be tested with each sample produced. It was laid down a processability range between 5% and 15% of the total mass of each sample.

Residues of granite, marble, schist, limestone and slate (black schist) were selected. The residues were mixed with the resin in a plastic container with a metal rod until a homogeneous mixture was obtained. After this phase, silicone moulds of adequate size were cast for the manufacture of samples and specimens. Demoulding occurred after 24h of hardening. Figure 3 shows the steps described.
In a first phase, still without scientific rigor, it was intended to master the processing technique of these materials.

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This step made it possible to specify the appropriate quantities of the different materials and to understand the relevance of particle size in composite manufacturing.

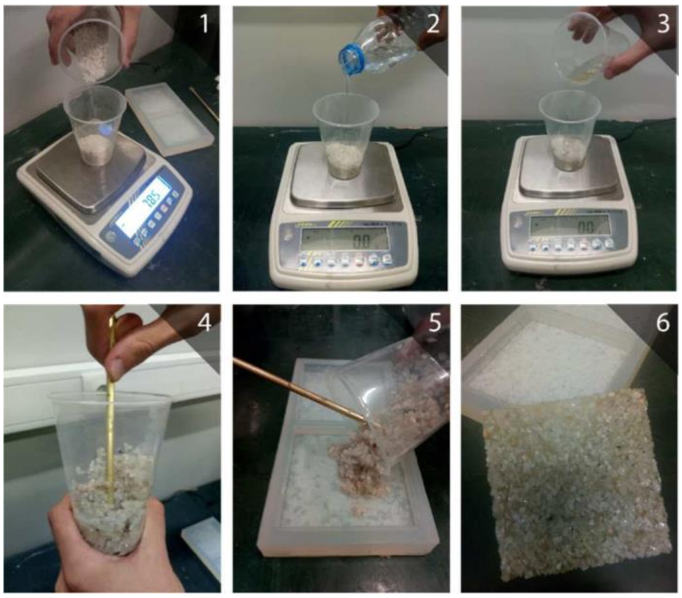

Figure 3. *Samples and specimens manufacturing process steps; 1) waste weighing, 2) resin weighing, 3) catalyst addition, 4) mixing, 5) silicone mould pour, 6) obtained sample.*

The acquired knowledge in the first phase allowed us to start a second phase of experimentation with quantified values and specimen's production, as indicated in Table 1. Particle size distribution was carried out through sieving, using sieves AS200 produced by Retsch (Germany).

Table 1. *Particle size distribution of the stone waste used to prepare the composites.*

	Granite (G)	Marble (M)	Schist (X)	Limestone powder (C)	Slate powder (A)
1st Stage Samples 1 to 12	Not determined	Not used	Not used	Not determined	Not determined
2nd Stage Samples 13 to 24	< 1.18 mm	< 1.18 mm; 1.18 - 2.36 mm; 3.36 - 4.76 mm	< 1.18 mm; 1.18 - 1.70 mm	Not determined	Not used
Specimens	Not used	0.84 - 2.38 mm	Not used	Not used	Not used

The test specimens were produced (Figure 4) in order to be tested according to the following standards: NP EN 14617-15_2010 - Determination of compressive strength;

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NP EN 14617-2_2010 - Determination of flexural strength (bending) (repealed);

NP EN 14617-1_2010 - Determination of apparent density and water absorption (repealed).

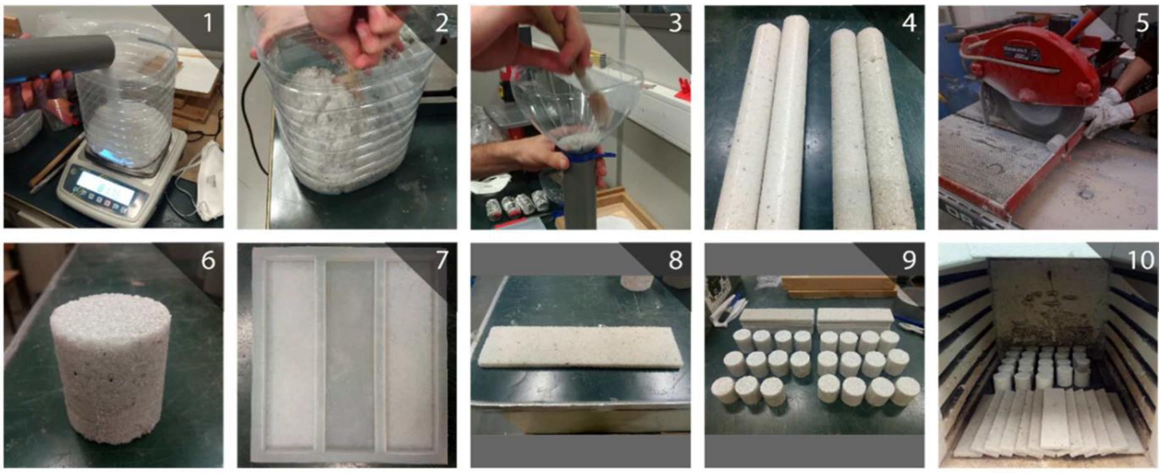


Figure 4. *Specimens manufacture; (1-3) mixture preparation and pouring into the PVC tubes, (4) obtaining the cylindrical composite rods, (5) cutting the specimens, (6) final cylindrical specimen, (7) plates shape specimens manufacture, (8) final plate shape specimen, (9) cylindrical specimens, e (10) drying in oven at 55ºC.*

Specimens of the same grain size were manufactured (0.84 – 2.38 mm), with minimum and maximum values in terms of resin quantity of 5% and 15%, respectively.

For the determination of compressive strength, apparent density and water absorption, European Standards state that specimens shall be 50 mm side cubes or cylinders with 50 mm of both diameter and height. Due to the fact that it is easy to produce cylindrical specimens, PVC tubes of sufficient length were used to obtain six specimens in each tube. Curing time of the composite was dynamic, that is, with a continuous rotation motion of the tubes in a roller drum, at 200 rpm for 24h.

For the flexural strength test, specimens (plate shaped) with the dimensions: 200 mm length, 50 mm wide and 10 mm thickness (this value varies depending on the final application) were manufactured using silicone moulds. After demoulding, the specimens were dried at 55ºC for 48h.

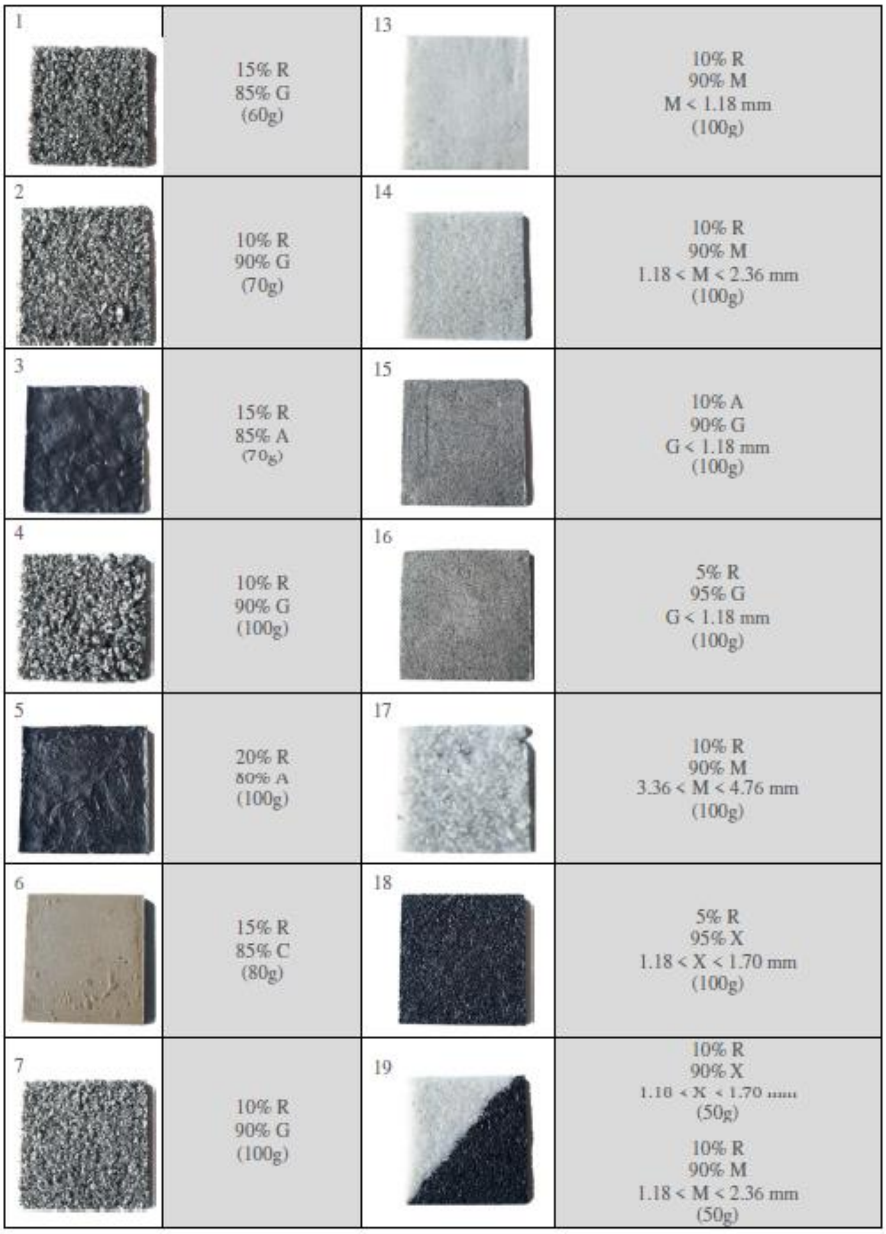
According to the normative procedures, the specimens should be dried at 70ºC for 48h. However, due to the possibility of degradation of resin properties at this temperature, drying was performed at 55° C, which is the post-cure temperature of the resin (Germanischer, 2014).

3.Results and Discussion

Table 2 presents the images of all samples obtained as well as the weight and percentage of resin and the different types of stones used. The codes used are: R (resin), G (granite), M (marble), A (slate powder), C (limestone powder), X (schist).

After performing the physical and mechanical tests on each set of 6 specimens (Figure 5), the properties presented in Table 3 for marble composites made with 5% and 15% of resin were determined. For comparative purposes and for the properties determined in the composites, the table also presents the mean values for Portuguese: sedimentary stones, metamorphic stones and igneous stones (Laboratório Nacional de Energia e Geologia, 2002).

Table 2. *Samples produced and main parameters (resin %, stone type and %, particle size distribution and weight).*



Sample	Parameters	Sample	Parameters
1	15% R 85% G (60g)	13	10% R 90% M M < 1.18 mm (100g)
2	10% R 90% G (70g)	14	10% R 90% M 1.18 < M < 2.36 mm (100g)
3	15% R 85% A (70g)	15	10% A 90% G G < 1.18 mm (100g)
4	10% R 90% G (100g)	16	5% R 95% G G < 1.18 mm (100g)
5	20% R 80% A (100g)	17	10% R 90% M 3.36 < M < 4.76 mm (100g)
6	15% R 85% C (80g)	18	5% R 95% X 1.18 < X < 1.70 mm (100g)
7	10% R 90% G (100g)	19	10% R 90% X 1.18 < X < 1.70 mm (50g) 10% R 90% M 1.18 < M < 2.36 mm (50g)

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8 	10% R 90% C (100g)	20 	7% R 93% C (50g) 7% R 93% M M < 1.18 mm (50g)
9 	15% R 85% A (80g)	21 	5% R / 95% M / M < 1.18 mm (25g) 5% R / 95% C (25g) 5% R / 95% G / G < 1.18 mm (25g) 5% R / 95% X / X < 1.18 mm (25g)
10 	15% R 42.5% G + 42.5% A (100g)	22 	5% R / 95% M / 3.36 < M < 4.76 mm (33.3g) 5% R / 95% M / 1.18 < M < 2.36 mm (33.3g) 5% R / 95% M / M < 1.18 mm (33.3g)
11 	15% R 42.5% G + 42.5% C (100g)	23 	10% R 90% M M < 1.18 mm (100g) Food colouring
12 	15% R 42.5% A + 42.5% C (80g)	24 	10% R 90% M M < 1.18 mm (100g) Food colouring

***Figure 5**. Tests carried out; (1) apparent density and water absorption, (2) flexural strength (bending) and (3) compressive strength.*

From the table analysis it can be concluded that any of the composites manufactured have both physical and mechanical properties less favourable to their application (lower: - apparent density, - flexural strength, - compressive strength; higher: - water absorption), than those presented by any of the natural stones lithologies. The 15% resin composite has better properties than the 5% resin composite. This finding was already expected, since the larger amount of low viscosity resin, that was used, contributed to a better filling of the voids left between the stone particles. This fact is corroborated when comparing the water absorption percentages:

specimens made with only 5% resin absorbed much more water.

Table 3. *Mean values (of apparent density, water absorption, flexural and compressive strengths rounded according with the respective European standards), for the marble composite manufacture. Comparison with bibliographic data [19] for sedimentary, metamorphic and igneous stones.*

	Composite 5%	**Composite 15%**	**Sedimentary stones**	**Metamorphic stones**	**Igneous stones**
Apparent density (kg/m^3)	1710	1990	2600	2720	2670
Water absorption (%)	13.9	0.1	1.3	0.1	0.3
Flexural strength (MPa)	3.8	15.4	16.8	23.2	17.7
Compressive strength (MPa)	10	43*	104	87	138

***** Mean value calculated only with results obtained in four specimens, due to problems with the remaining specimens.

The density of the resin — 1150 kg/m3 [18] — together with the pore content of the composite are responsible for its lower apparent density than natural stones, which may be an advantage when developing decorative products.

4.Proposal for implementation

The design proposals for new products with the developed composite took into account a methodology developed by the Design Engineering Department of the Technological University of Delft, Netherlands and by the Design department of the Polytechnic of Milan, Italy – Material Driven Design (MDD), which presents 4 steps to reach conclusions based on the available material and in its technical and experimental characteristics.

This methodology was specifically designed to conduct the entire design process with new materials, based on experimental results and questionnaires made to design students. The result was a set of images and sensory scales relative to the intended terms for the final product: “modern” and “tempting”, as well as visualizations of those same terms (Figure 7). These questionnaires helped to conclude on what features should be incorporated into the proposals.

Since the mechanical properties of the manufactured composites make it impossible to use them for the manufacture of structural products, the proposals presented are of a decorative nature. Taking into account the translucency characteristics of the marble samples and the questionnaire participants' suggestions, the application of the material will target objects used for illumination.

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Inspired by the conical shape of the volcanos, a process of the Nature that generates some stone types — the focus

of this study, one of the proposals is a table lamp made entirely from the mixture of marble grains and resin. It brings together the characteristics that came out from the questionnaire methodology described above, featuring a minimalist look, with the unique and serene colour of marble and a symmetrical geometry, which facilitates the manufacturing and demoulding process (Figure 8).

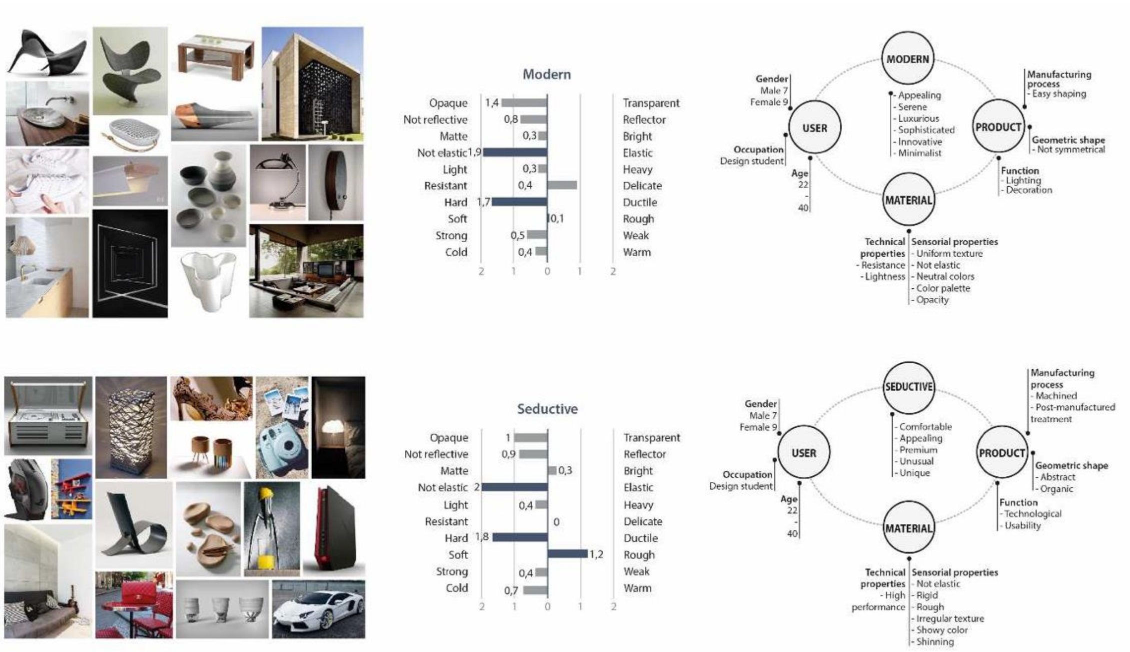

Figure 7. *Mood boards, sensory scales and visualizations for the terms "modern" and "tempting".*

Figure 8. *Application proposal of a table lamp using marble waste.*

The other proposal is based on the concept of joining together different stones, from samples 19 and 20, taking advantage from the contrast between dark and opaque schist grains and translucent and light marble grains (Figure 9); on the back was used a light source that highlights only the marble spots. This concept was tested by manufacturing the acronym of the Faculty of Engineering of the University of Oporto: FEUP, by combining schist and marble composites, manufactured with 10% of resin. It was verified that the light only passes through the marble, thus giving the desired effect. This proposal can be even more complex with the design of a world map (Figure 9).

Figure 9. *Marking and cutting of letters on cardboard (1-2), pouring the mixture around the letters (3-4), card removal and marble pouring after 24h (5-6), end result with light on the back (7) and render from another product in a living room (8).*

It should be noted that the resin used in the experimental phase does not have characteristics suitable for the type of suggested applications, since it changes colour with light and heat exposure. Ideally, a UV and heat resistant resin, such as an acrylic resin, should be used.

5.Conclusions

Mining of natural resources is one of the most important industries for the existence and continuous development of the human beings. As such, it will continue to exist and as the world population continues to increase, it is expected an increase in demand for those resource. As a result, even with continuous improvement of the mining and transformation processes, large amounts of waste will continue to be generated, of which most part will not be used.

The use of residues for incorporation into different products is nowadays a reality. However, utilization rates are still extremely low. This work aimed to develop composites based on different particles of schist, marble, limestone, slate and granite, mixed with epoxy resin. The obtained results, both in terms of physical and mechanical properties, limit their use in the manufacture of structural products (slabs for paving and cladding, Slabs and cut-to-size products for vanity and kitchen tops, etc.). However, it opens the opportunity for the creation of decorative objects. In this sense, two artefact proposals were presented, which took advantage of some stones the translucency, to use them to manufacture illumination objects.

The presented work creates an opportunity for the manufacture of decorative pieces, enhancing the natural stones economic circle. It is a small contribution for the reduction of the environmental impacts caused by

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waste generated in the mining and transformation processes of natural resources.

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Mapping Economic Change (Part 1): a Bibliometric Analysis of the Current State of Sustainable Economics Initiatives

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Abstract

Together with the arising awareness for the ecological and social effects of the current economic system, which have been extensively reported from the 70s, the financial crisis of 2008 was interpreted as a turning point for the search and creation of a new economic paradigm more stable and sustainable. Several proposals, both at the theoretical and grassroots level, emerged as possible alternatives, in some cases gaining worldwide visibility (for instance, the Peace Nobel Prize to Muhammad Yunus for Microcredit), in others helping localities to reorganize themselves and survive with parallel systems. The scope of this research is to map the state of the art of these initiatives of sustainable economics - which we define as an economy with concern for environmental and social issues at its core - in the specific case of academic publications. We identified ten different keywords which resulted to be the current most relevant proposals and we used bibliometric tools based on online academic databases to collect data about the distribution and variation of these initiatives in the last 20 years. Moreover, we created citation network maps to measure and visualize the relatedness of the topics and the interconnection of their authors, using direct citations, bibliographic coupling and co-occurence of key words. As results, we found in general an increasing interest in the topics, especially after the financial crisis of 2008. Furthermore, the territorial distribution is mainly concentrated in some areas, which is reflected also by an affiliation-concentration around some key institutions. Finally, we found that in general the concerns of the different topics are quite similar and integrated, but the level of communication between the authors is low and polarized inside some clusters. As conclusion, we call for a stronger integration and communication among the different exponents of these initiatives, as well as for their unification under a common umbrella that reconnects the academic field with the existing local practices, creating a bridge between theory and practice of alternatives to the current economic system.

Keywords: Sustainable Economics, Bibliometrics, Network Mapping, Post-growth, Circular Economy

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1.Introduction

What is sustainable economics?

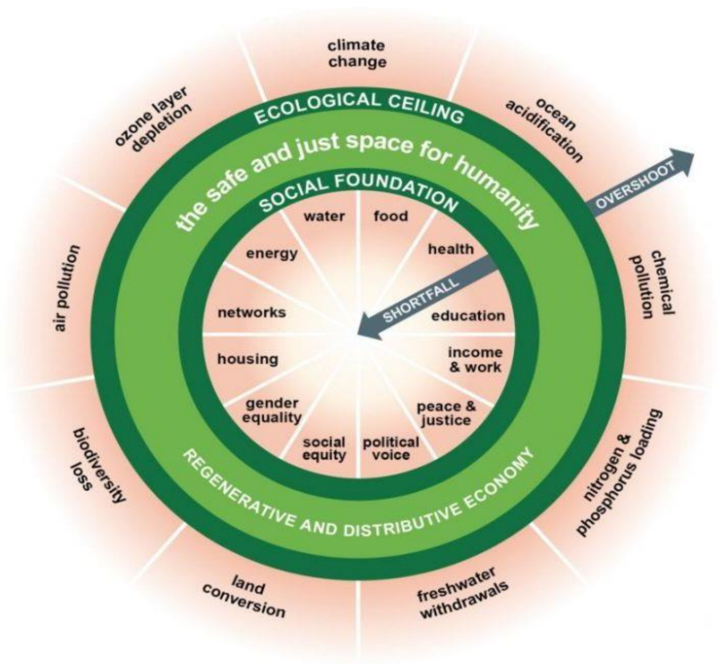
When we talk about sustainability and development, the most common definition used is still the one from the Brundtland's report, which states that "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987 in Lorek and Spangenberg, 2014, p.33). However, this inflationated quote is often separated from the following part, less known, that more clearly completes the definition: "It [sustainable development] contains within two key concepts:

- the concept of needs, in particular the essential needs of the world's poor, to which overriding priority should be given; and
- the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs." (ibidem)

Thirty years ago, the report was already defining which should be the focus of sustainable development: human needs fulfilment respecting environmental limits (Lorek and Spangenberg, 2014). It created two boundaries, a social floor and an environmental ceiling, placing sustainability in the between. The concept was revolutionary because it introduced a new element, the limit, in the development discussion, which until then was concentrated only on the social side and considering growth as the economical solution for poverty.

Nowadays, the concept has been reclaimed by Kate Raworth, who in her book Doughnut economics: seven ways to think like a 21st-century economist (2017) has graphically designed the two boundaries—social and ecological—that together encompass human wellbeing:

***Figure 1**: Doughnut economy. Source: Raworth 2017*



The inner border delimits the social foundations, below which we find a deficit of wellbeing, like hunger, ill and illiteracy. These twelve dimensions are extracted from the Sustainable Development Goals formulated by the United Nations in 2015 and are measured through the corresponding indicators[1]. The outer border shows the ecological limitations, beyond which there is an overpressure on the planet capacities and its life-supporting

systems, with consequences like climate change, ocean acidification, and biodiversity loss. The nine dimensions, with the corresponding indicators, are derived from a framework that reproduces the Holocene-like conditions of Earth, considered as the optimal physical state for the survival of the system (Raworth 2017).

Inside this framework, the goal of development is wellbeing (Costanza et al. 2018), and the goal of economics is to find, organize and maintain this balance between human needs and planetary boundaries. We could therefore consider an economy as sustainable if it simultaneously satisfies these two requirements: to improve the wellbeing of people living below the social margin, remaining inside the limitations imposed by the ecological necessity to preserve the environment (Lorek and Spangenberg 2014). That means that any scenario outside these criteria is unstainable: socially, when not meeting the needs (that strongly differ from the wants!) of humans, and environmentally, when using and consuming the resources beyond the environment's carrying capacity (ibidem). Between these two boundaries, there is an ecologically safe and socially just space in which all of humanity has the chance to thrive (Raworth 2017) and to reach a sustainable state of wellbeing.

How can we define wellbeing?

For Costanza et al. (2018), it is the outcome of a convergence of factors, including good human mental and physical health, greater equity and fairness, good social relationships and a flourishing natural environment. Economics should have the fundamental goal of achieving sustainable wellbeing with dignity and fairness for humans and the rest of nature.

However, a main issue with sustainable economics is the difficulty to leave behind the concept of growth. So far the discussion was focused on how innovation, technology and growth could solve the current ecological problems, bringing into a lock-in situation and to a vicious circle where the measures taken for short term relief increase the problems instead of solving them in the medium to longer term (Lorek and Spangenberg, 2014). In fact, technological optimism dominated the discussion, stating that innovation will be able to solve any environmental problem. Efficiency and green were the magic words used to re-legitimate the system, but they are not sufficient to remain inside the planetary boundaries. This issue was already pointed out in 1971 by Ehrlich and Holdren (in Lorek and Spangenberg, 2014), with their I= P*A*T equation, where the (environmental) impact (I) is a result of three components: population (P), affluence (A), and technology (T). Affluence is defined as GDP per person and technology as the resource consumption per unit of GDP, or eco-efficiency. According to all forecasts, the world's population will

[1] The SDGs are 17 goals formulated in 2015 by UN aimed to be reached by 2030. Each goal is divided in targets that refer to specific issues, which are measured through indicators by different agencies. For further information: https://unstats.un.org/sdgs/ https://sustainabledevelopment.un.org/content/documents/3233indicatorreport.pdf

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grow and GDP is expected (and desired) to grow too (increase of P and A), so in order to maintain the current environmental impact (which actually should be reduced to remain inside the Holocene-like conditions), technology should be capable of compensate all these variables (Lorek and Spangenberg, 2014). Moreover, this perspective doesn't consider the rebound effect (Friends of Earth Europe, 2018): higher efficiency brings to higher consumptions, because with the same resources it is possible to produce more. Taking into account the precautionary principle, the technological development (T) is unforeseeable and there is an urge to reduce the environmental impact (I): it is therefore recommendable to slow the increase of the world population P and to effectively decrease resource consumption per capita too (A) to avoid disasters in the event that technology fails to solve the problem (Lorek and Spangenberg, 2014). This means to aim to sufficiency instead of efficiency.

Nevertheless, the predominant economic paradigm is a monopoly focused on efficiency, as it doesn't allow the presence of different systems, and is characterized by recurrent structural crises. Moreover, according to Goerner,et al. (2009), efficiency is the other side of resilience, and sustainability is a function of the two: they are essentially complementary, as the optimisation that increases efficiency automatically reduces resilience[2]. In order to have a sustainable system, it is necessary to have both of them: a system with strong efficiency is too fragile, whereas a system with high resilience may suffer from stagnation.

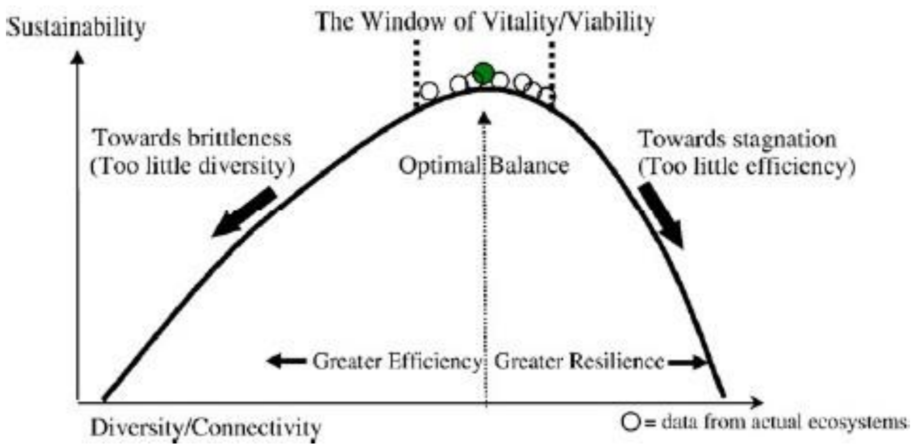

Figure 2: *Sustainability as a function of efficiency and resilience. Source: Goerner et al. 2009*

The diversity and richness of different visions and proposals give resilience and therefore robustness to the system, creating alternatives that can survive to the systemic problems of the neo-classical model. Nevertheless these proposals, and more extensively the sustainable approach, are still a minority in the economic field and are marginal in comparison with the current economic system.

Why do these proposals still result as a minority if the Bruntland report stated already 30 years ago the importance of having environmental limitations and to focus on improving human conditions?

Throughout its history, economics has experienced episodes of pluralism and episodes of a dominant

[2] Efficiency is defined as *the network's capacity to perform in a sufficiently organized and efficient manner as to maintain its integrity over time* (May, 1972 in Goerner et al. 2009, p.77), whereas resilience is *the reserve of flexible fall-back positions and diversity of actions that can be used to meet the exigencies of novel disturbances and the novelty needed for on-going development and evolution* (Holling, 1973, 1986; Walker et al., 2006, in ibidem)

orthodoxy.

Since the 70s, with the collapse of the Bretton Woods system, a major paradigm shift brought to the establishment of a "dominant orthodoxy in economics, characterized by a formal, econometric approach and a broadly neoclassical framework" (Glötzl and Aigner 2018, p.1). Heterodox approaches existed, but they were marginal, and the modus operandi of the system made even more difficult for them to arise: "once a paradigm becomes dominant, network effects lead to positive-feedback processes that create path dependencies and stabilize the discipline's orthodoxy" (Sterman and Wittenberg, 1999 in Glötzl and Aigner, 2018, p.1). Dobusch and Kapeller (2012b) graphically represented this phenomenon, after classifying the different paradigms existing in the economic field, as reported in figure 3.

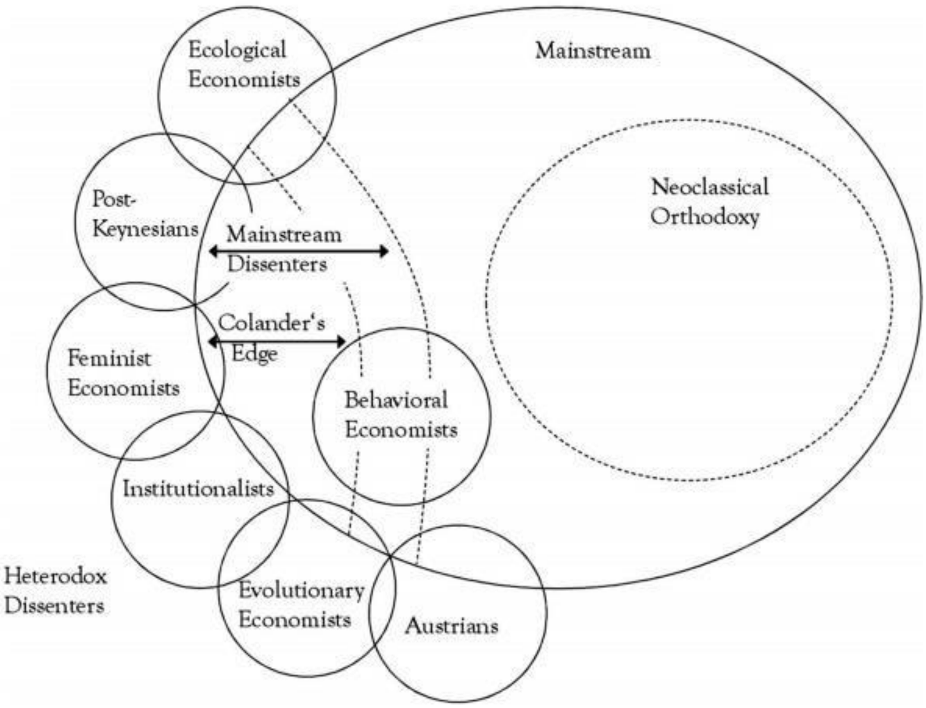

Figure 3:*Paradigms in the economic discourse. Source: Dobusch and Kapeller (2012b) in Glötzl and Aigner (2018)*

The image shows the presence of a hard core of orthodox economy, the "neoclassical", which is the main subject area of the mainstream paradigm. Heterodox approaches lie outside and communicate with the mainstream section mainly by criticising it. However, some approaches, which are not into the neoclassical orthodoxy core and are close to the heterodox ones, are gaining more and more visibility and recognition: behavioural economics, for instance, whose authors received the Nobel Prize in the last years, still belongs to the mainstream sphere but differs with some assumptions of the neoclassical approach. However, most of heterodox approaches still embrace some central factors that characterize traditional economics, such as growth, accumulation and competition. We tried then to make a distinction between the main concepts and assumptions behind traditional and alternative economics, which are reported in table 1:

Table 1*: Main concepts of traditional and alternative economics. Source: The Author*

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Main Concepts of traditional economics	Main concepts of alternative economics
Growth	Sufficiency/Well-being
Rationality	Behaviour/Context
More	Better
Money as a goal	Money as a means
Accumulation	Balance
Competition	Cooperation
Environment and society as externalities	Economics embedded in environment and society

The table shows the differences between the two approaches, which significantly disagree on their vision of human nature, and therefore on how humans interact in an economic environment and which is the role of economics. In fact, natural sciences (and reality) seems to agree more with the assumptions of the alternative approaches than the traditional ones.

With this research, our goal is therefore to find out which are these new proposals related to sustainable economics and how are they gaining visibility in the academic field. Our research question is then: Which are the initiatives and the discourses that currently have most relevance in the field of sustainable economics? How are they interrelated? (How are they territorially distributed?)

Our objectives of the research thus are:

To map the state of the art of the academic contributions in the field of sustainable economics and their interconnections;

To analyze the distribution of academic publications, related to the initiatives, and their degree of reciprocity.

2.Methods

To assess our research, focused on the new initiatives in the field of economics that are looking for alternative and more sustainable proposals, we decided to combine a bibliometric analysis[3] with a qualitative review of scientific publications related to the topic. Our goal is to map the different discussions in the field, to weight and analyse their diffusion and to find possible connecting points. Our hypothesis is in fact that several initiatives are rising, which can be complementary and integrated into a common and comprehensive proposal, but the visibility they are gaining in the academic arena strongly differs, and their development proceed on parallel paths.

For our research we relied on two online databases of academic publications: Scopus and Web of Science. We chose Scopus as main search engine because it is “the world’s largest abstract and citation database of peer-reviewed literature, [which includes] scientific journals, books and conference proceedings, covering research topics across all scientific and technical disciplines, ranging from medicine and social sciences to arts and humanities”[44]. Moreover the database provides smart tools to track, analyse and visualize the results of the research. For the citation-network mapping we used Web of Science, as it provides complete data about the publications and their references that can be elaborated by bibliometric software.

[3] Bibliometrics is the scientific analysis of publications that seeks to identify the major fields of study within and across scientific disciplines and the most influential publications, research institutions, and researchers in each of these fields

[4] https://www.elsevier.com/solutions/scopus, Retrieved on the 30/06/2018

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We limited the time framework to publications published between 2000 and 2018 in order to visualize the evolution of the topics in the last 20 years and notice possible differences before and after the 2008 financial crisis; in addition, with the purpose of avoiding biases with papers which use similar key words but that are not associated with sustainable economics, we restricted the research to some specific areas:

Environmental Sciences

Social Sciences

Economics, Econometrics and Finance

Business, Management and Accounting

Decision Sciences

Arts & Humanities.

Regarding the language, publications in all languages were included in order to get access and take into consideration the territories where the topics are spreading, as well as to reflect on which ones get more relevance in certain countries. Most of the publications in Scopus report the title, abstract and keywords in English besides the language it is used in the full article. However, we know that the research will in any case favour Anglo-Saxon publications as the key words chosen are in English.

Key words

With the aim of identifying which are the most relevant new proposals in the field of sustainable economics, we conducted a publication research using key words. Our goal was to cover as much as possible the different domains in which economics is subdivided, and that we classified in 5 core areas:

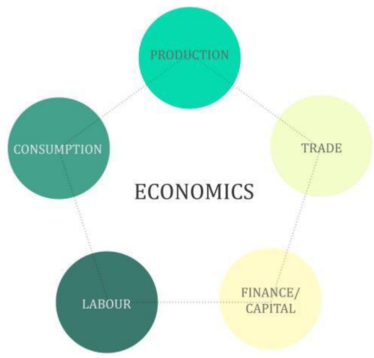

Figure 4. *The 5 domains of economics. Source: The Author*

As we couldn't find a comprehensive study that considers all the different proposals that are currently arising, we adopted a "snowballing approach" to find the initiatives related to sustainable economics that currently have most relevance and that cover the five domains of economics previously presented. The concepts resulting from this research were:

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- Basic Income
- Circular Economy
- Community Banks
- Complementary Currencies
- Degrowth/Post-growth
- Economy for the Common Good
- Ethical Banking/Finance
- Ethical Consumerism
- Fair Trade
- Green Economy
- Local Exchange Trading System
- Microcredit
- Shorter workweek
- Social Business
- Solidarity Economy
- Sufficiency Economy

We then searched through Scopus, applying the previously mentioned limitations, these key words to find the relative number of publications5[5]:

Table 2: *Total number of publications per category. Source: The Author*

Key words	**N° Publications**
Basic Income*	505
Circular Economy*	1521
Community Banks & Ethical Banking/Finance*	256
Complementary Currencies & LETS*	140
Degrowth/Post-growth*	401
Economy for the Common Good	7
Ethical Consumerism	105
Fair Trade*	1484
Green Economy*	1238
Microcredit*	950
Shorter workweek	27
Social Business*	361
Solidarity Economy*	217
Sufficiency Economy	71

As selection criteria for the quantitative analysis and the citation network mapping, we stated a minimum of 140 publications per category. We then resulted with 10 key words (marked in the table with *) that cover all the 5 domains of economics and at the same time result to have relevance in the academic field with a consistent number of publications.

2.2Quantitative Research

After the selection process, we collected data regarding the publications using the Scopus search engine. In particular, for each category we gathered data about:

Number of publications per year: total amount of publications in the time framework considered (from 2000 to 2018);

[5] For the research strings used, refer to the annex. The number of publications refers to the 30/06/2018.

- Authors: name of the authors that published most articles in the category;
- Affiliation: universities and/or institutions with most publications;
- Country: the country where the author or the institution publishing the articles belongs.

We then elaborated these data through a statistical software (Microsoft Excel) to transform them in graphs and maps. We moreover compared the data of the 10 categories between them, in order to notice the difference and similarities according to these criteria. In the result section we report the tables and the charts deriving from this process.

2.3Citation Network Mapping

The main goal of bibliometric network visualization is to graphically show the relations between the parts of a system. A bibliometric network consists of nodes and edges: the nodes can be for instance publications, journals, researchers, or keywords; the edges indicate relations between the nodes (Van Eck and Waltman, 2014). In our case, the system is the academic field and the nodes are the researchers/authors who published articles related to sustainable economics. We will use citation network-based bibliometric mapping to investigate about the relations and their strength between the different initiatives arising in sustainable economics. The rationality behind is to verify whether and which authors belonging to different proposals are close to which other ones: the closer they are, the most likeable their topics are to be connected and integrated. Bibliometric network visualization allows analysing large amounts of complex bibliographic data in a relatively easy way by visualizing the core aspects. However, it is based on simplification, and therefore as a limitation it implies a loss of information (Van Eck and Waltman, 2014).

Several techniques are used in bibliometrics to show the relatedness of the nodes: co-citation, bibliographic coupling, co-authorship, co-occurrence, direct citation (Boyack and Klavans, 2010). For our research, we decided to use direct citations and bibliographic coupling for the references, and co-occurrence for the key words. “Two publications are bibliographically coupled if there is a third publication that is cited by both publications” (Kessler, 1963 in Van Eck and Waltman, 2014, p.3). In other words, bibliographic coupling is about the overlap in the reference lists of publications. “The larger the number of references two publications have in common, the stronger the bibliographic coupling relation between the publications” (ibidem). Direct citations, instead, sometimes referred to as cross citations, offer a more direct indication of the relatedness of publications compared with other techniques. However, they usually lead to very sparse networks. Finally, regarding co-occurrences of keyword, it can be defined as “the number of publications in which (two) keywords occur together in the title, abstract, or keyword list” (Van Eck and Waltman, 2014). They therefore report whether and which topics are discussed across different fields of study.

For our research, we extracted the full report and references data of the publications belonging to the 10 selected categories through Web of Science. We then elaborated these data with a bibliometric software (VOSviewer). The programme works with a distance-based approach: the nodes in the bibliometric network are positioned in such a way that the distance between them approximately indicates their relatedness. Therefore, the smaller the

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distance between two nodes, the higher is their relatedness. Each circle represents a researcher: large circles represent researchers that have many publications associated with the identifications criteria, whereas small circles represent researchers with few publications. In general, the closer two researchers are located to each other in the visualization, the more strongly they are related (Van Eck and Waltman, 2014).

3.Results and Discussion

As previously mentioned in the methodology section, we selected 10 key words that we used as research topics in Scopus. We then collected the data regarding each key word according to different criteria (number of publications, authors, affiliation, country). Here following we will report the data resulting from this research.

3.1 Number of Publications

We considered the time-framework 2000-2017, excluding 2018 as when we were writing this paper the year wasn't concluded yet. The following table reports the number of publications per year for the 10 categories selected:

Table 3: *Number of publications per year per category. Source: The author. Data from Scopus*

	Basic Income	Circular Economy	Community Banks & Ethical Finance	Complementary Currencies & LETS	De/Post-growth	Fair Trade	Green Economy	Microcredit	Social Business	Solidarity Economy
2000	2	0	2	3	0	8	0	8	1	0
2001	6	0	5	2	0	15	2	17	1	0
2002	10	0	4	2	0	16	1	17	1	0
2003	8	0	6	2	1	38	0	13	0	1
2004	20	3	18	3	1	27	0	20	1	2
2005	26	4	5	6	2	44	3	26	2	1
2006	20	14	3	3	1	61	0	23	2	0
2007	13	28	9	6	3	94	3	32	3	0
2008	14	13	15	0	2	92	2	31	4	2
2009	23	50	12	8	8	105	16	57	7	9
2010	15	51	9	9	13	125	27	67	22	6
2011	38	57	17	4	18	100	77	50	16	9
2012	8	30	19	5	50	140	103	66	36	12
2013	36	31	22	11	56	119	144	82	43	10
2014	20	63	14	13	27	138	152	91	47	32

2015	44	93	19	14	46	102	172	99	59	38
2016	49	209	26	20	71	107	208	107	51	22
2017	97	464	35	16	63	91	218	93	36	46
Total	449	1110	240	127	362	1422	1128	899	332	190

We graphically reported the table, comparing the variation in the number of publications per year:

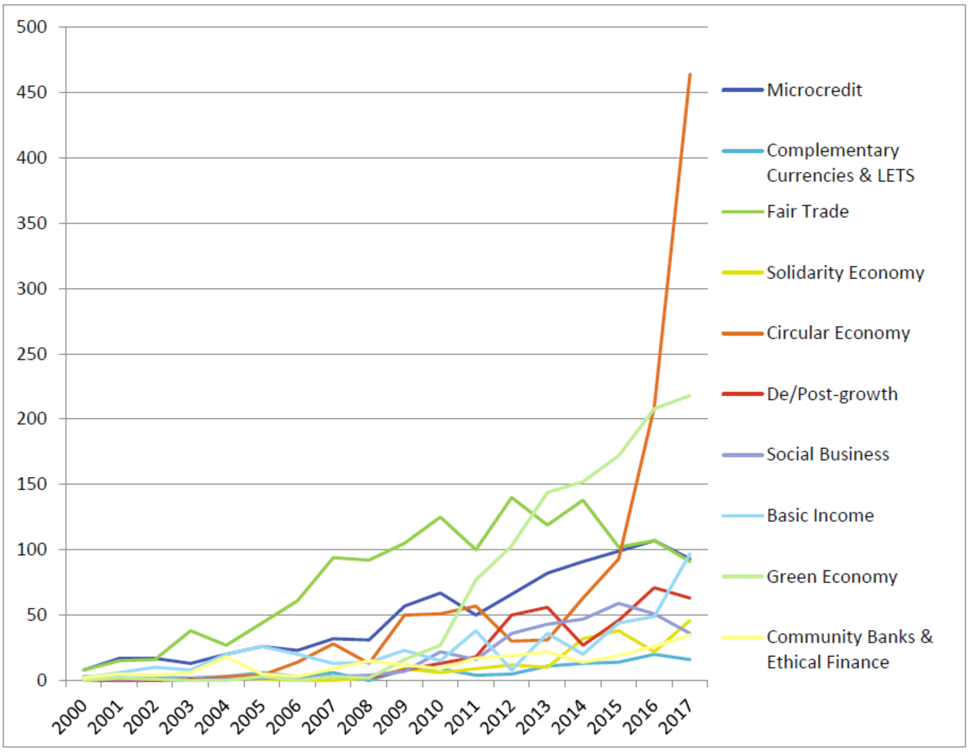
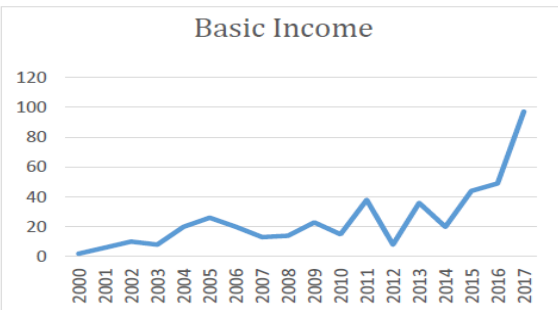
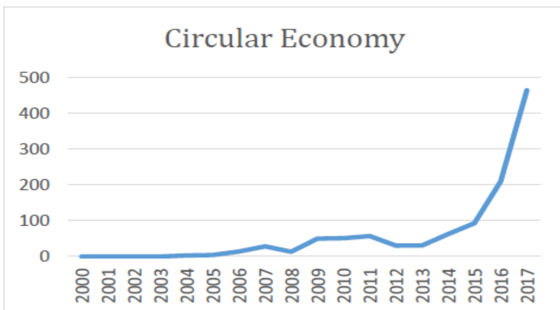


Figure 5*: Comparison: number of publications per year. Source: The Author. Data from Scopus*

Besides all the topics started with very few publications at the beginning of the time framework considered, we can notice a general growth but with relevant differences during the following years. Analyzing the singular key words, we notice a sudden increase for some (Circular Economy, De/Post-growth, Green Economy) and a more constant increase for other ones (Community Banks, Complementary Currencies, Microcredit, Fair Trade).





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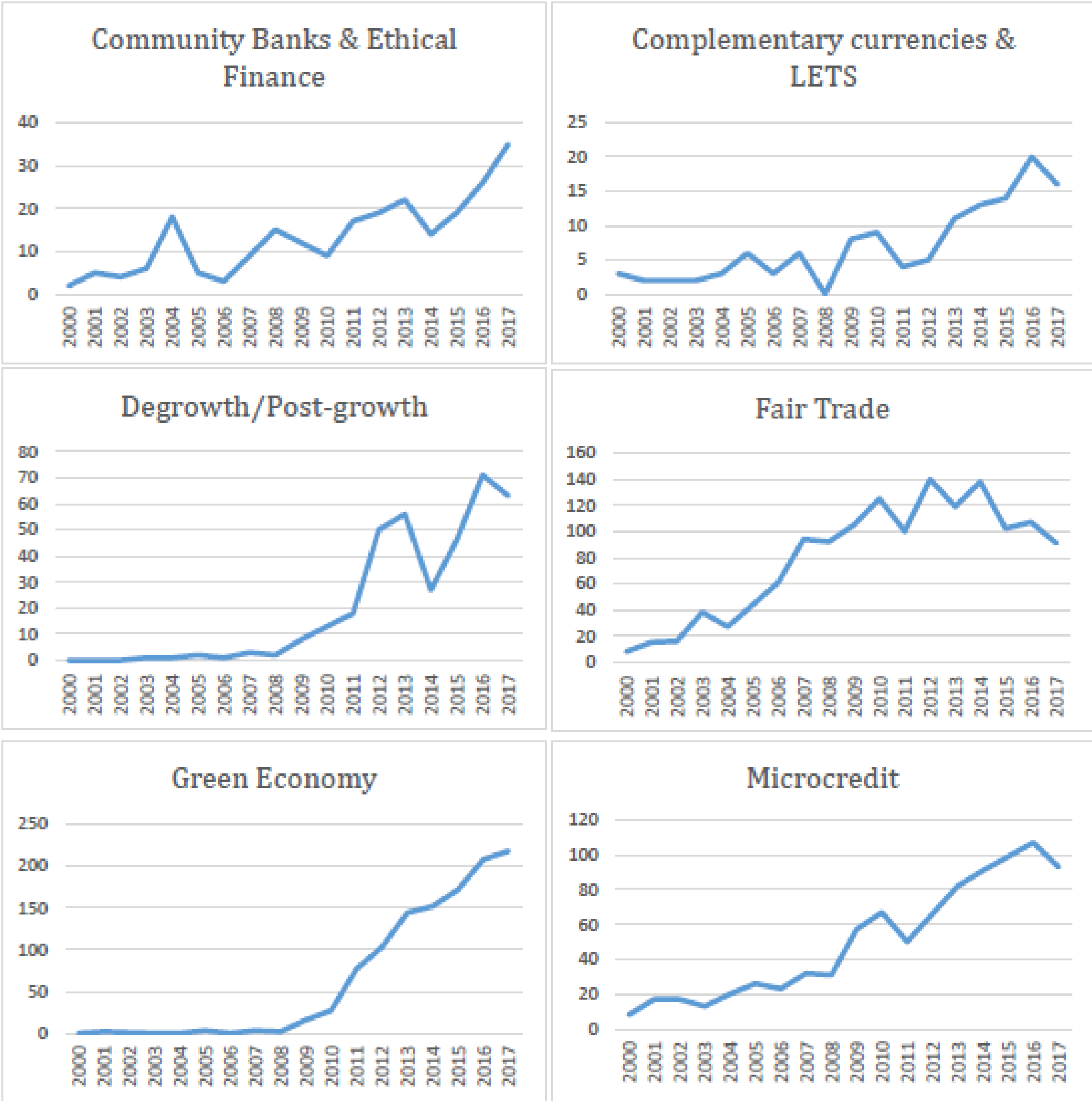
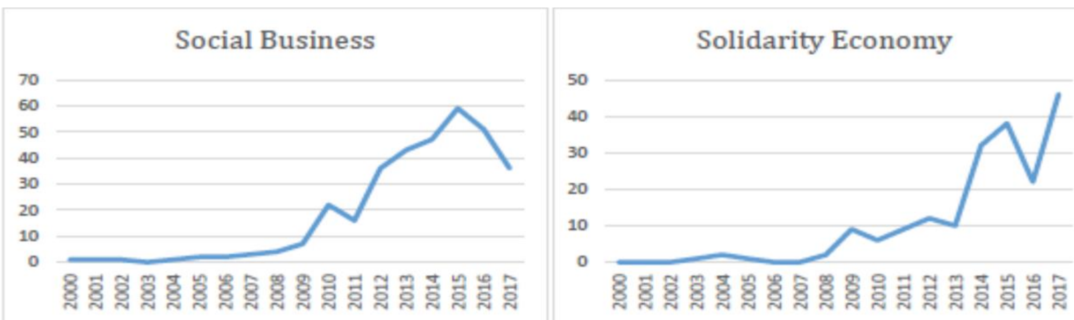


Figure 6: *Variation number of publications per each topic. Source: The Author. Data from Scopus*



Apart from small variations, all the topics result to be increasing. In particular, as it is more evidently showed by figure 7 (next page), the exponential growth started with 2008, when the financial crisis broke out.

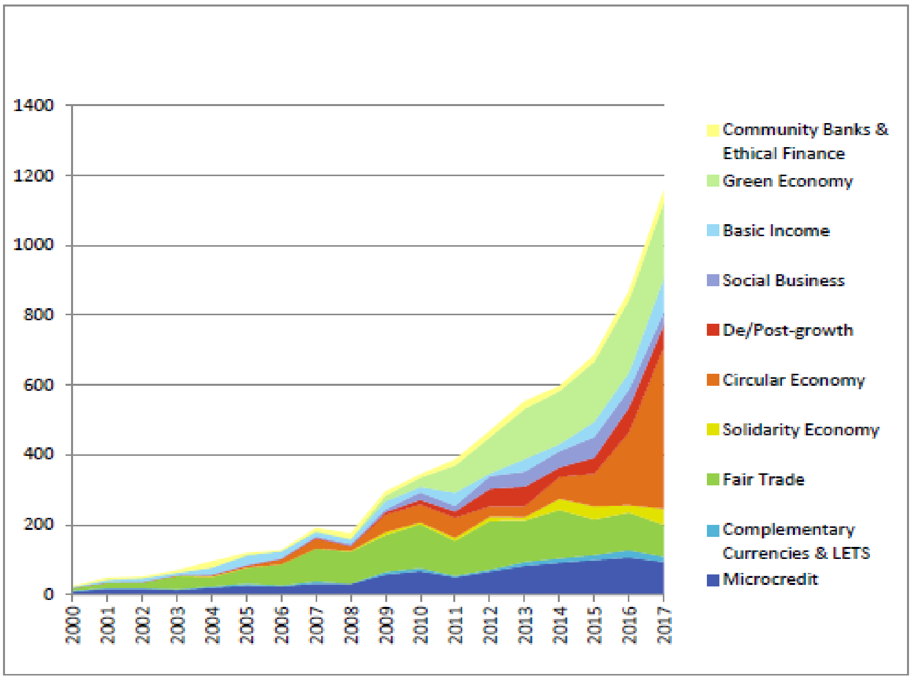


Figure 7: *Publications per year: cumulative. Source: The Author. Data from Scopus*

The graph reports also the total number of publications in the field of sustainable economics (according to the subdivision in different categories and initiatives that we used in this research). It shows therefore a general increase of interest and discussion about the topic, especially after the economic crisis, which was however concentrated on some specific topics (mainly Circular Economy and Green Economy).

3.2 Authors

We considered for each topic the ten authors that published most articles in the category and the relative number of publications, in the time framework 2000-2018. The results are reported in the following table:

Table 4: *Number of publications per author per category. Source: The Author. Data from Scopus*

Authors/Topic	N° publications	Authors/Topic	N° publications
Basic Income		**Fair Trade**	
De Wispelaere, J.	14	Raynolds, L.T.	19
Widerquist, K.	11	Becchetti, L.	16
Stirton, L.	8	Stefańska, M.	12
Fumagalli, A.	5	Lyon, S.	11
Van Parijs, P.	5	Davies, I.A.	10
Zelleke, A.	5	Doherty, B.	10
Birnbaum, S.	4	Ruben, R.	10
Caputo, R.K.	4	Bacon, C.M.	9

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Jordan, B.	4	Huybrechts, B.	9
Marazzi, C.	4	Shaw, D.	9
Circular Economy		**Green Economy**	
Geng, Y.	16	Nhamo, G.	17
Bocken, N.M.P.	13	Dudin, M.N.	10
Geng, Y.	11	Apsalyamova, S.O.	9
Chertow, M.	8	Khuazhev, O.Z.	9
Kopnina, H.	7	Musango, J.K.	8
Niero, M.	7	Brent, A.C.	7
Purnell, P.	7	Caprotti, F.	7
Zhu, Q.	7	Khachir, B.O.	6
Bakker, C.	7	Antikainen, R.	5
Bilitewski, B.	6	Bailey, I.	5
Community Banks & Ethical Finance		**Microcredit**	
Kagan, A.	7	Al-Mamun, A.	11
Dilger, R.J.	6	Guérin, I.	10
DeYoung, R.	5	Karlan, D.	10
Acharya, R.N.	4	Morduch, J.	9
Berger, A.N.	4	Jebarajakirthy, C.	8
Becchetti, L.	3	Mazumder, M.N.H.	7
Cutcher, L.	3	Serrano-Cinca, C.	7
Evans, M.D.	3	Gan, C.	6
Ferreira, F.A.F.	3	Gutiérrez-Nieto, B.	6
Hein, S.E.	3	Khandker, S.R.	6
Complementary Currencies & LETS		**Social Business**	
Seyfang, G.	10	Berg, G.A.	4
Lietaer, B.	5	Ferreira, M.J.	4
North, P.	5	Grove, A.	4
Hudon, M.	4	Moreira, F.	4
Blanc, J.	3	Seruca, I.	4
Dini, P.	3	Golfarelli, M.	3
Dodd, N.	3	Kiron, D.	3
Fantacci, L.	3	Palmer, D.	3
Longhurst, N.	3	Phillips, A.N.	3
Peacock, M.S.	3	Vatrapu, R.	3
De/Post-growth		**Solidarity economy**	
Kallis, G.	16	Gaiger, L.I.	7
Demaria, F.	7	Rakopoulos, T.	5
Martinez-Alier, J.	6	Gutberlet, J.	4
O'Neill, D.W.	6	North, P.	4
Schulz, C.	6	Safri, M.	4
Xue, J.	6	Borowiak, C.	3
D'Alisa, G.	5	Cato, M.S.	3
Gunderson, R.	5	Grasseni, C.	3
Muraca, B.	5	Healy, S.	3
Schneider, F.	5	Kalogeraki, S.	3

We will further analyse the author's relationships in the citation network section. However, it is interesting to notice that there are no authors belonging to more than one category, and therefore that result as main exponents of more than one topic.

3.3 Affiliation

We therefore considered for each key word the ten universities and/or institutions with most publications. The data are reported in table 5:

Table 5: *Number of publications per institution per category. Source: The Author. Data from Scopus*

Institution/Topic	N° publications	Institution/Topic	N° publications
Basic Income		**Fair Trade**	
University of Oxford	9	Colorado State University	35
Universita degli Studi di Torino	8	University of Kentucky	21
Tampereen Yliopisto	7	Universite de Liege	16
University of Bath	7	University of Oxford	15
Universite Catholique de Louvain	6	Universita degli Studi di Roma Tor Vergata	15
Universitat de Barcelona	6	University of Wisconsin Madison	14
University of Manitoba	6	York University	14
University of York	6	Wageningen University and Research Centre	13
University of California, Los Angeles	6	Radboud University Nijmegen	13
University of East Anglia	5	Cardiff University	13
Circular Economy		**Green Economy**	
Delft University of Technology	45	The Bucharest University of Economic Studies	31
Chinese Academy of Sciences	43	Universiteit Stellenbosch	17
Tsinghua University	37	University of South Africa	15
Lunds Universitet	29	Wageningen University and Research Centre	14
University of Leeds	20	University of Cambridge	12
University of Cambridge	20	Academy of Economic Studies, Bucharest	11
Cranfield University	17	University of Oxford	11
Danmarks Tekniske Universitet	17	Chinese Academy of Sciences	10
Shanghai Jiao Tong University	17	Universitatea Petrol-Gaze din Ploiesti	10
Aalto University	17	University of Hull	10
Communityr Banks & Ethical Finance		**Microcredit**	
Federal Reserve Board	8	Université libre de Bruxelles ULB	15
Arizona State University	4	Yale University	15
La Trobe University	4	The World Bank Group	13
Kwame Nkrumah University of Science and Technology	4	Cornell University	12
University of South Alabama	3	New York University	11
Universitat de Valencia	3	University of Manchester	10
Newcastle University, United Kingdom	3	Multimedia University	10
The World Bank Group	3	University of Dhaka	9
University of Ghana	3	University of Oxford	9
University of South Carolina	3	University of Bath	9
Complementary Currencies & LETS		**Social Business**	
University of East Anglia	11	Copenhagen Business School	7
London School of Economics and Political Science	7	California State University Channel Islands	7

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Université libre de Bruxelles ULB	6	Universidade de Sao Paulo – USP	6
University of Liverpool	5	ESSEC Business School	5
University of California, Berkeley	5	Universidade do Minho	4
Univerzita Hradec Kralove	3	Indiana University	4
University of Oxford	3	Universitat St. Gallen	4
Alma Mater Studiorum Universita di Bologna	3	Alma Mater Studiorum Universita di Bologna	4
York University	3	MIT Sloan Management Review	3
Integral Science Institute	2	Loughborough University	3
De/post-growth		**Solidarity economy**	
Universitat Autònoma de Barcelona	36	Panepistimio Kritis	7
UAB Institut de Ciencia i Tecnologia Ambientals	32	Universidade do Vale do Rio dos Sinos	6
Institucio Catalana de Recerca I Estudis Avancats	16	Universidade Federal de Sao Carlos	5
University of Leeds	8	Universidad del Pais Vasco	5
University of Melbourne	7	Universite Catholique de Louvain	4
Friedrich Schiller Universitat Jena	7	Universidad de Buenos Aires	4
Helsingin Yliopisto	6	University of Victoria	4
Masaryk University	6	Drew University	4
Miami University	6	University of Liverpool	4
Aalborg Universitet	5	Universitat Lausanne Schweiz	3

We gathered the data of all the categories in order to find the 15 institutions that resulted to have most publications in the field of sustainable economics, reported in graph 8:

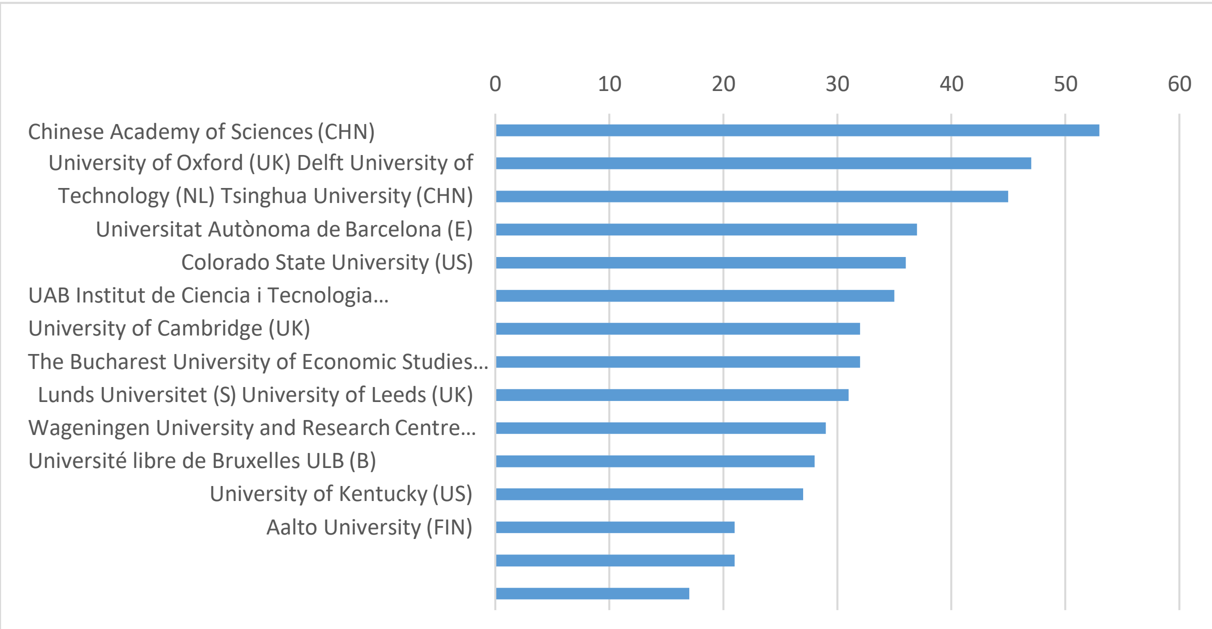
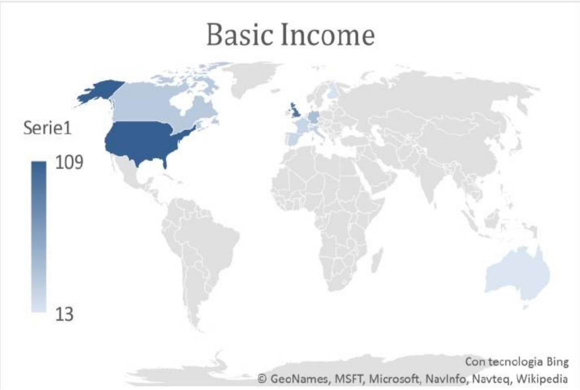


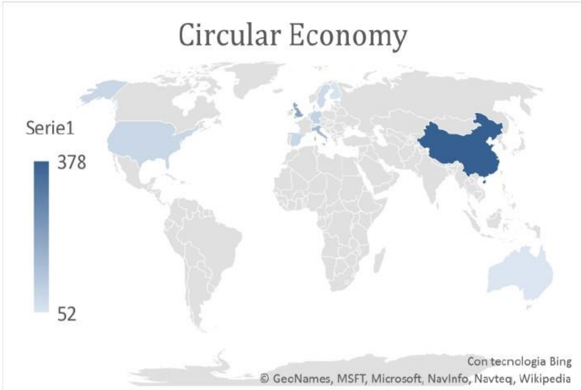
Figure 8: *Affiliation: Top 15 institutions. Source: The Author. Data from Scopus*

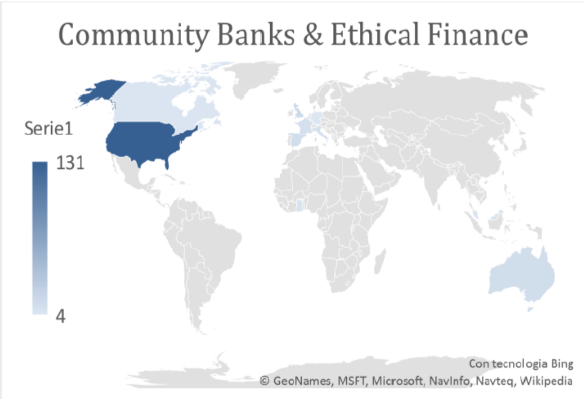
With the exception of two American and two Chinese universities, all the other institutions are from Europe. We further analyzed this aspect in the territory section.

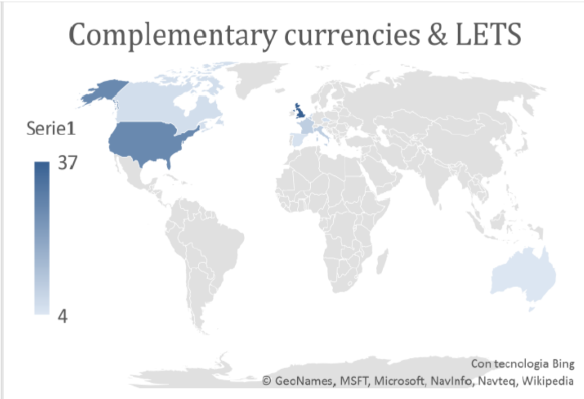
3.4 Country

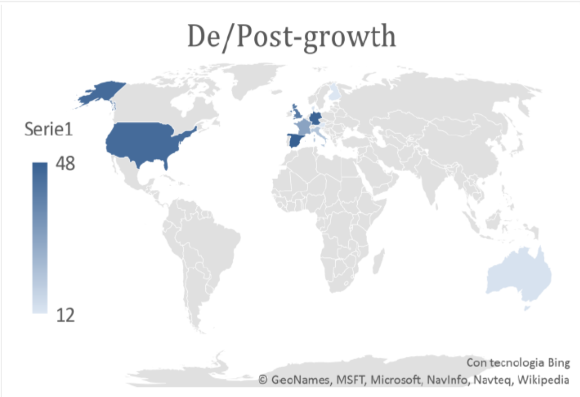
The following maps report the distribution of the publications in the countries per category[6]:

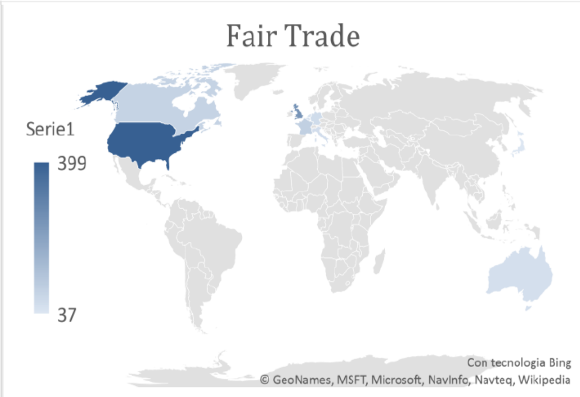


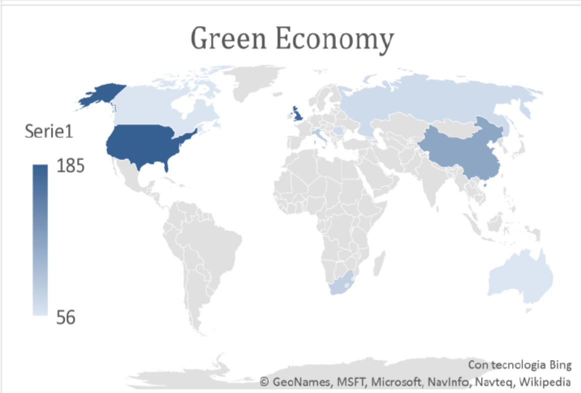


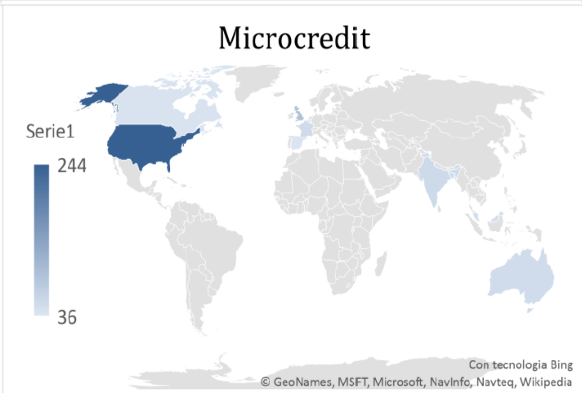












[6] For the table with the related data, refer to the annex

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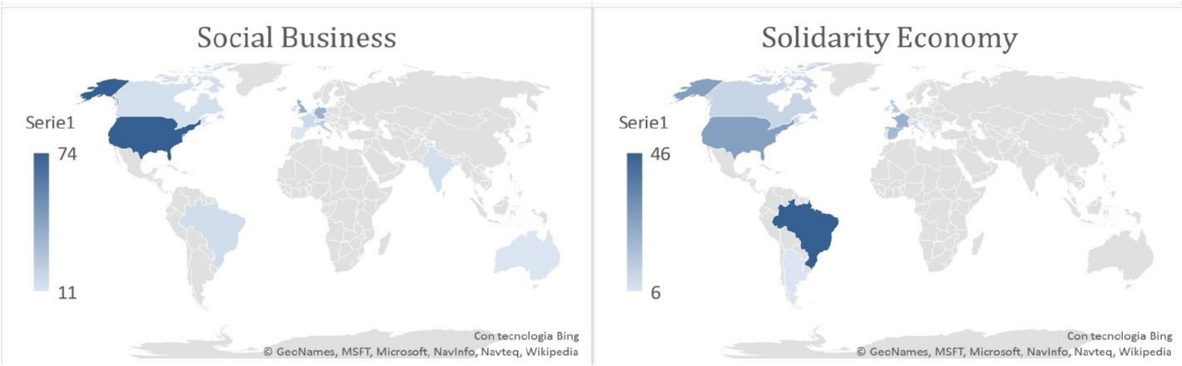

Figure 9: *Territorial distribution of publications per category. Source: The Author. Data from Scopus*

In general most of the publications are in North America, Western Europe and Australia. However, there are some significant exceptions: the dominant country in Circular Economy is China, which together with Russia stands out also for Green Economy. India emerges in Microcredit and Social Business whereas Solidarity Economy is mainly concentrated in South America. We gathered these data to visualize the general distribution of the publications worldwide:

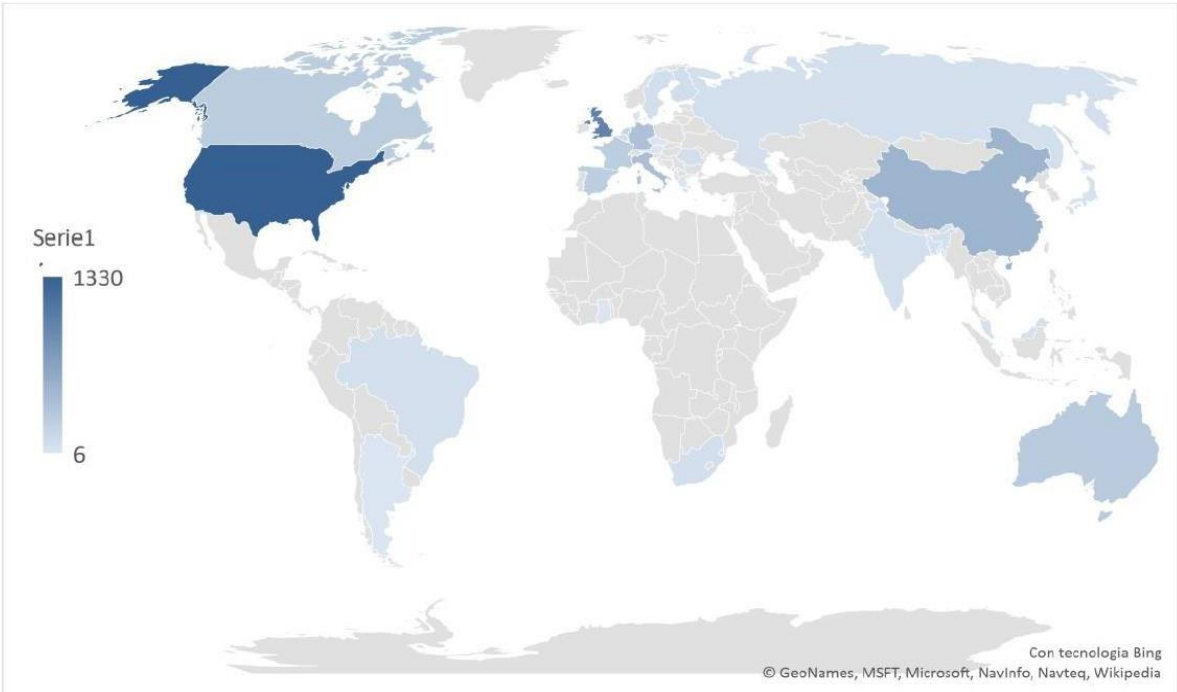

Figure 10: *Territorial distribution of total publications. Source: The Author. Data from Scopus*

The map reflects the previous graphs: sustainable economics discussions are concentrated around some areas that are North America, Western Europe, Australia and China (for some specific topics). Russia, South America and India follow. The big absents are Africa (with the exception of South Africa and Ghana), Middle East, South East Asia and Central America.

The following chart reports the top ten countries with most publications. As expected in the methodology, we found English speaker countries, especially United States and UK. They are followed by China, and then only by Western European countries. However, these latters slightly differ from the countries appearing in the affiliation graph: only Spain and Netherlands were appearing between the top institutions, whereas here Italy, Germany and France stand out.

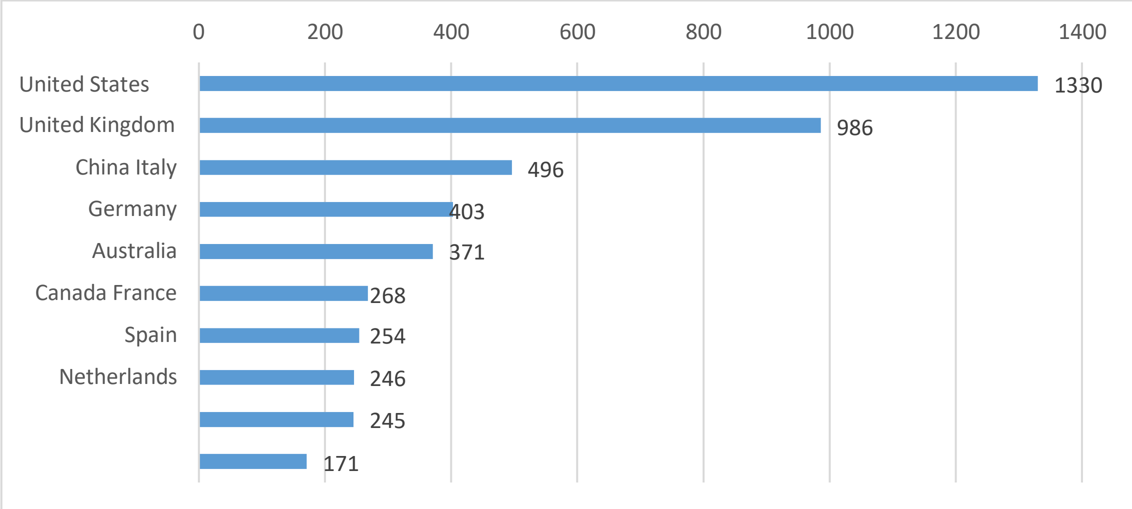

***Figure 11**: Top 10 countries per total publications. Source: The Author. Data from Scopus*

3.5 Citation Network Mapping

We created the network clouds elaborating the references data of all the publications of all the categories considered. As already mentioned in the methodology section, the distance between the topics in the graph reports their relatedness. We associated each cluster with the correspondent topic considering the authors and the publications they refer to. The first image reports the network based on direct citations, the second on bibliographic coupling:

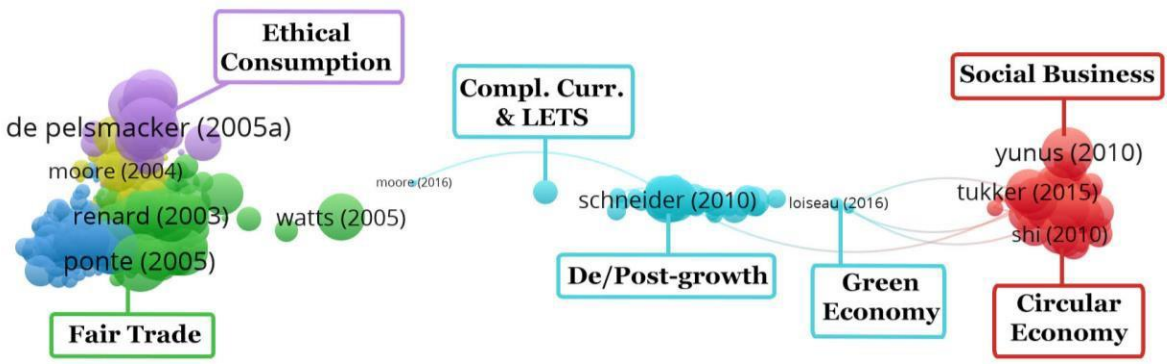

***Figure 12:** Direct citations network. Source: The Author. Data from Web of Science*

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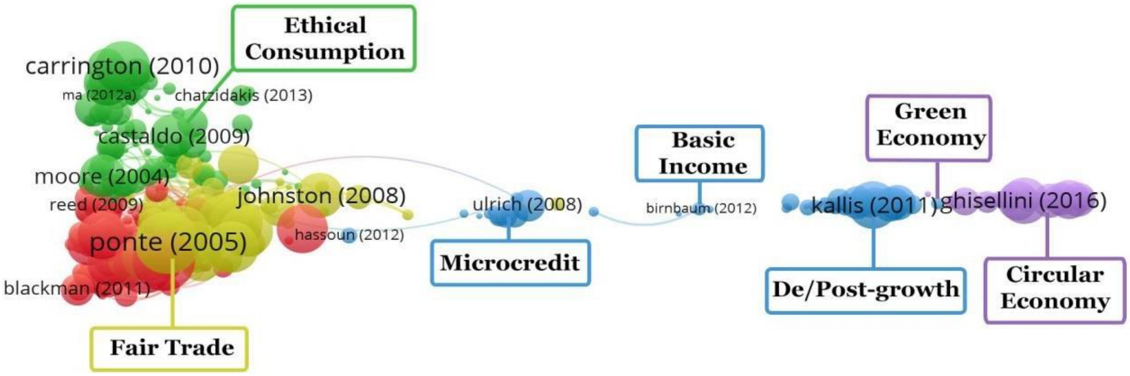

Figure 13: *Bibliographic coupling network. Source: The Author. Data from Web of Science*

The different presence of the topics in the graphs reflects the algorithm of the programme. Those that do not have enough references to other publication in the network do not appear at all (in this case Community Banks & Ethical Finance and Solidarity Economy). The two charts result quite similar and complementary: both report at the extremes two topics, Circular Economy and Fair Trade (this latter strongly related to Ethical Consumption), with De/Post-growth mediating in the middle. Green Economy always appears between De/Post- Growth and Circular Economy, whether the topics between Fair Trade and De/Post-Growth differ according to the bibliometric technique used.

We then elaborated the same data considering the co-occurrence of terms, which means the use of the same terms across different publications. In the second picture we also considered the time dimension.

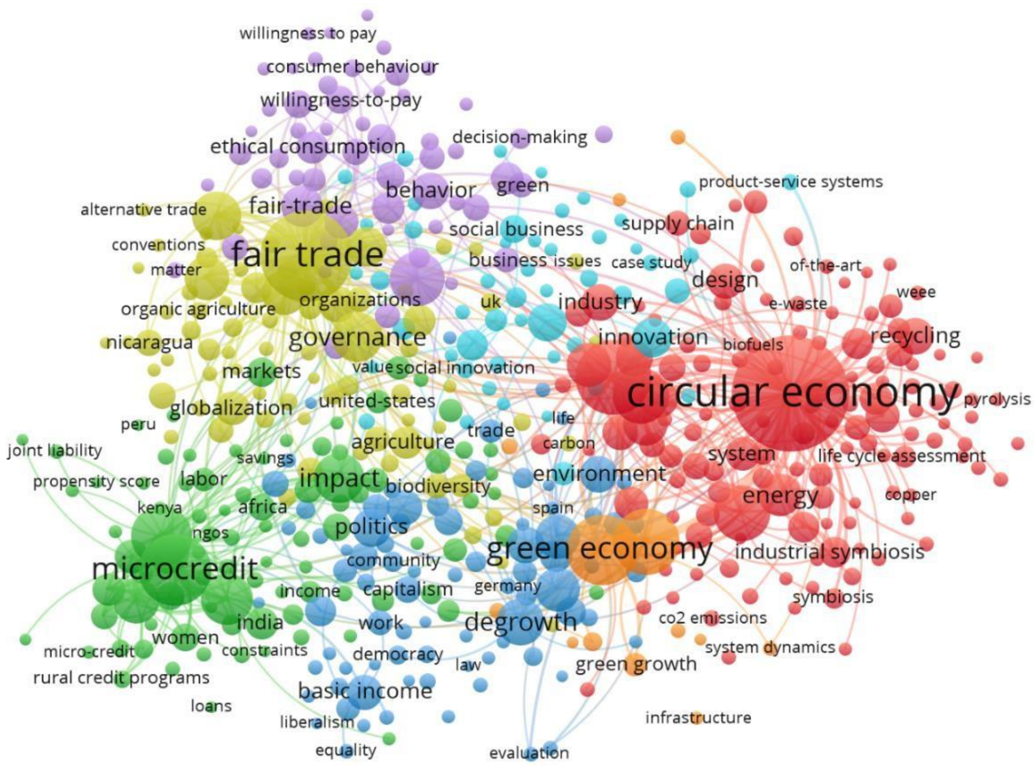

Figure 14: *Co-occurrence of terms network. Source: The Author. Data from Web of Science*

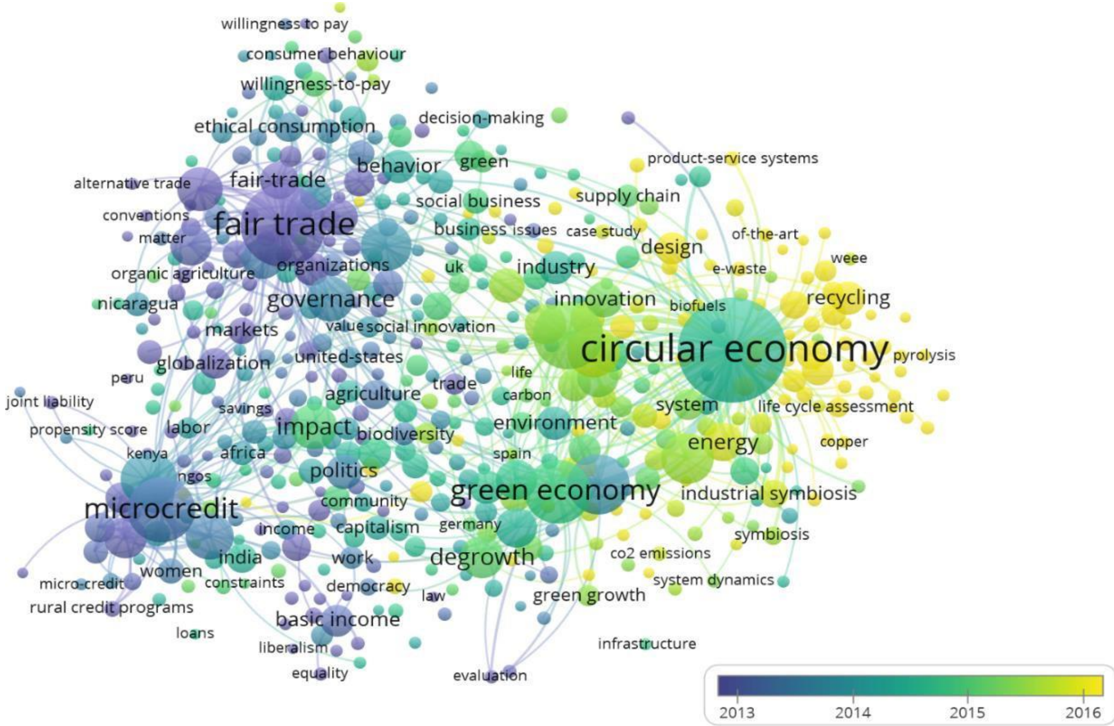

Figure 15: *Co-occurrence of terms network with time dimension. Source: The Author. Data from Web of Science*

When considering the terms, we notice a general higher integration of the topics, with less polarization as it happens considering the authors. The different currents in sustainable economics appear therefore quite homogenously integrated and focused around similar key issues. However, the authors writing about them do not result as easily communicating and talking to each other, polarised inside their clusters. Regarding the time dimension, we notice a general shift from microcredit and fair trade towards circular economy, which, considering also the previous graphs appears the top discussed topic at the moment.

3.6 Discussion: Distribution

From the findings we acknowledge that there has been a general trend of all the initiatives examined: they started with very few publications at the beginning of the time framework considered (2000) and, apart from small variations, they all increased. However, besides the general growth there are relevant differences among the topics: the majority followed a constant and slow increase, whereas some of them faced a sudden escalation (Circular Economy, De/Post-growth and Green Economy). In particular, this exponential growth started with 2008, date that is linked with the financial crisis. It seems therefore that the economic crisis was interpreted as a call for new, more stable and sustainable alternatives to the mainstream paradigm. Nevertheless, the focus was especially on more efficient and green approaches than those concerned with social issues: Circular Economy and Green Economy resulted to be the two strategies adopted as solutions for addressing the environmental and economic crisis, leaving aside the social implications of unequal wealth (and ecological) distribution.

Regarding the institutions that resulted most interested in the topics, we find mainly European universities, together with two Chinese and two universities from US. These results seem slightly in contrast with the typical

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distribution of academic papers related to economics: as Aigner et al. (2018) noticed, generally more than 70% of the top-cited papers in economics are from the United States, and more than one half of these papers are associated with a group of highly influential universities, all located in the United States (University of Chicago, Harvard University and MIT). It seems therefore that this phenomenon, better known as "lite licensing institutions", is not that strong if we consider the specific section of publications related to sustainable economics, with these universities not even appearing in the top fifteen. However, the absence of institutions from the global South could have different interpretations: on one hand it may reflect a sort of "affiliation concentration", which means that researchers leave their countries to go to bigger institutions where they can get a certain visibility more easily; on the other hand it may report a higher interest to reform the actual economic paradigm by rich countries, those that were more hit by the economic crisis of 2008, but that at the same time already faced industrialization and its ecological effects. Moreover, in not-English speaking countries, local language is often used to talk to local fellows, groups of interest and politically influential people, who frequently do not speak English, whereas English is used to communicate at an international level. Thus, the more the publications are practical and oriented towards influencing and transforming local and national realities, the less likely they will appear in English.

A similar pattern can be noticed observing the geographical distribution of the publications: we found that most of the papers come from North America, Western Europe and Australia. We already mentioned in the methodology chapter a possible bias created by searching the key words in English. However, besides most of the West-European countries are not English speakers, they result among those with the highest academic interest for these topics. It is important anyway to notice that these institutions are better integrated in the western first world scientific community. BRICS reported too a growing interest for these topics, focusing on different ones: Brazil for Solidarity Economy, Russia and South Africa for Green Economy, India for Microcredit and Social Business and finally China for Circular Economy. We can already find here a different approach towards "sustainable development" among these countries: Brazil and India seem to focus on the social issues, where Russia, China and South Africa are more concerned with the environmental side.

Some areas resulted as "big absents": Africa (with the exception of South Africa and Ghana), Middle East, South East Asia and Central America have almost no publications. However, this trend could be related to the above-mentioned effects of researchers' brain drain, the higher concern with ecological and post-crisis issues of rich countries and language bias. It seems anyway a "lost occasion" for the global South to recognize and look for economic alternatives, like those proposed in this research, as new and different paths of development, and to consider them as key strategies for a more social and ecological sustainable approach to economics and policy making.

3.7 Discussin: Authors and Topics Relations

Analysing the bibliometric results, we encounter similar findings when using the direct citations and the bibliographic coupling: the topics are disposed in a linear way, in a sort of continuum which sees on one side Fair Trade and on the other side Circular Economy, with the other topics disposed around and between them. They show therefore a polarization in clusters, where few authors and key words seem to be related to each other. There is a strong relation between Fair Trade and Ethical Consumerism: indeed, Fair Trade is actually based on the purchase power of consumers and their ability to change the market with more ethical purchasing choices

(Perna, 1998). A similar strong relation appears among Circular Economy, Green Economy and Social Business: these initiatives are focused on the production side, and on the importance of enterprises to have at their core ecological (and social in the case of Social Business) issues to be addressed. The financial initiatives are always positioned between Fair Trade and De/Post-growth, as well as those related with social issues: they result therefore quite distant from the authors concerned mainly about environmental solutions. The intermediate position of De/Post-growth could exactly represent this double concern for social and ecological issues, but at the same time it could be a sign of broader dialogue with the different initiatives existing.

However, the findings are significantly different when we consider the co-occurrence of terms: we can notice a general higher integration of the topics, with several connections and closer positions. Besides their authors, which are polarised inside their clusters and that do not result as easily communicating and talking to each other, the different proposals in sustainable economics seem quite homogenously integrated and focused around similar key issues. The same topics that appeared as separated and not related in the citation network, and therefore in contrast or opposite, result on the contrary complementary and interdependent when considering their concerns. Regarding the time dimension, the co-occurrence network reflects the distribution patterns noticed in the quantitative analysis: from Fair Trade to Microcredit, two topics mainly related to social issues and focused on the global South, there has been a general shift towards Circular Economy, the top discussed topic of the moment, which is however related only to the environmental face of sustainability, applied mainly in rich countries and is compatible with a neoliberal economic system.

4.Conclusions

With this research, we pointed out and reported the current trends of academic publications related to sustainable economics. To assess that, we used bibliometrics, carrying out a quantitative analysis, together with a network citation mapping. From this analysis some important points emerged, which we extensively reflect on in the discussion section. In general it emerged a high interest of sustainable economics for proposals which are focused on “efficiency” and “green” as solutions for sustainability, but that in fact use these magic words to re- legitimate the system and which are, as we already pointed out in the theorical chapter, not sufficient to remain inside the planetary boundaries. Nevertheless, number of publications does not mean real initiatives: the visibility of some topics in the academic field does not necessarily reflect which ones are in reality the most spread and common worldwide. It is quite likeable that there is a gap between them, especially for those that regard local and bottom-up initiatives, as usually these have a lower visibility. Moreover, in our research we are not assuming an evaluative bibliometric approach: this means that we do not consider that the quality of the proposals derives from the number of citations or publications.

Indeed, few proposals are outside the traditional narrative that considers growth as an unavoidable and essential strategy for development, but the existing ones (mainly Degrowth) actually result as those dialoguing most with the other initiatives. The question could therefore be whether these proposals are truly trying to reshape economics towards more sustainable models, or just trying to adjust some minor flaws or using “green washing” as propaganda. However, it is important to acknowledge what the co-occurrence of terms reports: besides resulting as isolated, these initiatives are as a matter of fact complementary, and integrating them together in a broader framework could actually be a strategy to give them more relevance, visibility but above all effectiveness. A key aspect that appeared is the importance and necessity of connection among the initiatives.

The gap is present not only between the already implemented experiments at the local level and the academic

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world, but above all among the principal exponents, which are not communicating to each other or trying to be integrated into a broader proposition. This lack of unity and cooperation may have the effect to weaken the visibility and the effectiveness of these new movements, as well as to send the message of a possible incompatibility of the proposals. As we showed, in fact there is an overlap in terms of objectives and concerns, and the unification of the initiatives under a common umbrella is not just feasible, but strongly recommended. Finally, to reconnect the academic field with the existing local practices may strengthen and mutually help each other even more, creating a bridge between theory and practice of alternatives to the current system.

Annexes:

Methods:

Research strings:

Basic Income:

TITLE-ABS-KEY ("basic income") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Circular Economy:

TITLE-ABS-KEY ("circular economy") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Community Banks & Ethical Finance:

TITLE-ABS-KEY ("community banks" OR "ethical banking" OR "ethical finance") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT- TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Complementary currencies & LETS:

TITLE-ABS-KEY ("alternative currencies" OR "complementary currencies" OR "local exchange trading system") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Degrowth/Post-growth:

TITLE-ABS-KEY ("degrowth" OR "post-growth") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Economy for the Common Good:

TITLE-ABS-KEY ("economy for the common good") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI "

) OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Ethical Consumerism:

TITLE-ABS-KEY ("etichal consumerism") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR

LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Fair Trade:

TITLE-ABS-KEY ("fair trade") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Green Economy:

TITLE-ABS-KEY ("green economy") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Microcredit:

TITLE-ABS-KEY ("microcredit") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Shorter Workweek:

TITLE-ABS-KEY ("shorter workweek" OR "reduced working hours") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Social Business:

TITLE-ABS-KEY ("social business") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Solidarity Economy:

TITLE-ABS-KEY ("solidarity economy") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Sufficiency Economy:

TITLE-ABS-KEY ("sufficiency economy") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (

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Mapping Economic Change (Part 2): a Qualitative Analysis of the Current State of Sustainable Economics Initiatives

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Abstract

In the last years several economic proposals, both at the theoretical and grassroots level, emerged in different parts of the world to address the environmental and social issues that the current economic paradigm left behind. Some of them gained worldwide visibility and managed to enter into the mainstream discourse of sustainability (by instance, the Circular Economy), others remained local experiments with low international echo (e.g.: the Complementary Currencies). In combination with the data extract from a previous study (Mapping economic change Part1: a bibliometric analysis of the current state of sustainable economics initiatives), in this research we selected 10 different key words that represent the current most relevant initiatives of sustainable economics - which we define as an economy with concern for environmental and social issues at its core – in order to carry out a qualitative analysis within the academic field. We investigated about the common and key characteristics of these proposals, in order to derive some hypothesis about their difference in visibility, distribution, approach and scope. We categorized these proposals according to three criteria: economic domain (consumption, labour, production, finance/capital, trade), type of initiative (bottom up or top-down) and scale (local, national and international). We moreover organized them into a scheme which orders the key words on two axes: radical- conservative (closeness of the topic to traditional or alternative economic approaches) and environmental-social (whether the focus of the initiative is more towards the ecological or the social field). As results, we found that those proposals focused on top-down approaches, on an international level and close to mainstream visions of economics, currently have higher visibility in the academic field. However, in our study we moreover demonstrate that these initiatives are not opposed to each other, but complementary: in fact, as part of the conclusion, we propose a possible scheme to integrate all these proposals into a comprehensive and integrated plan for a more sustainable economy. We believe that presented in this shape, these initiatives can gain more easily visibility, and above all result as more effective and robust in proposing themselves as a practical and independent alternative to the current economic paradigm.

Keywords: Sustainable Economics, Post-growth, Bibliometrics, Circular Economy, Sufficiency

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1.Introduction

Despites claiming itself as a science, economics actually is culture (Banet-Weiser and Castells, in Castells 2017). And a cultural change is more difficult and requires more time than a scientific adaptation. Economic practices are human practices, and therefore are determined by humans that personify their way of thinking, interests, values and projects (ibidem). There is not an abstract, external, imposed economic logic, but an adaptation to social and cultural practices for inertia, which are embedded in institutions. The current economic paradigm is based on specific values (selfishness, rationality, competition, accumulation) which represent only a part of human behaviour, but this is claimed to be the real "nature" of man. This system therefore favours practices that are coherent with its vision, leaving aside alternatives that have different values and modus operandi. However, new models of production, consumption and trade are being formulated and put into action daily by millions of people that are rethinking economics, and new institutions are created by those that don't feel represented by the present ones.

At the beginning of the XXI century, the economic challenges consistently differed from those of the XIX and XX centuries, when the basis of the current economic system were founded. At that time the fundamental question was how to achieve growth and produce prosperity; nowadays the issue is how to thrive without growth and live with the essential (Kallis in Castells 2017). The present goal and concern are not how to dismantle growth, but how to create a wealthy alternative that doesn't require growth; how to found a new economic science for a new economic system (ibidem). An alternative vision of development was presented already in the 1970s by the ecological economist Herman Daly (in O'Neill, 2015), who developed the concept of steady-state economy, that may be defined as "an economy where the main biophysical stocks and flows are stabilised, and where material and energy flows are kept within ecological limits" (p. 1214). However, stable doesn't mean sustainable: the definition of a steady-state economy focuses entirely on the biophysical side, without considering other socio-economic indicators (O'Neill, 2015). This concept was then complemented by proposals that introduced the importance of the social dimension in the post-growth discussion, especially focusing on wellbeing as the final goal of these new economic models.

Hence, new economic models are necessary, and they do exist and have already been formulated despite being hardly considered by police-makers. The predominant discourse in politics and economics is still focused on growth, affirming that there are no viable and practical alternatives proposed by the critics of the current system. However, as Castells and Hlebik notice (in Castells, 2017), several initiatives emerged in the social edges of the advanced financial-capitalistic context as possible alternatives to solve daily problems or as projects for a new economy based on different values. Some of them were isolated and focused on specific issues (like Microcredit, Fair Trade, Complementary Currencies), others were integrated into a more comprehensive and theoretical framework that was trying to rethink the predominant vision (like Degrowth or the Solidarity Economy). Some rely on a top-down approach, others on bottom-up initiatives, and consider different scales (local, national or international). According to the geographical area where these initiatives arose, they took a different denomination, creating even more diversity but also difficulty to classify them. Nevertheless, they share in general the common goals of sustainable economics - to improve the wellbeing of people living below the social margin, remaining inside the limitations imposed by the ecological necessity to preserve the environment (Lorek and Spangenberg, 2014) - some focusing more on the environmental side, others on the social one. We based our study on these proposals, exploring how they are distributed and discussed in the academic field and how much relevance they are gaining. The objectives of this research are therefore:

- To identify the new narratives related to more sustainable and ethical economic proposals and analyze their key aspects;
- To investigate about the motivations and the implications deriving from the different distribution and visibility of the publications related to the topics.

2.Methods

As this paper is part of a broader research, which combines a bibliometric analysis[1] with a qualitative review of scientific publications related to the topic of sustainable economics, we based it on the same key words selected for the first part (Mapping economic change Part1: a bibliometric analysis of the current state of sustainable economics initiatives). As we couldn't find a comprehensive study that considers all the different proposals that are currently arising, we adopted a "snowballing approach" to find the initiatives related to sustainable economics that currently have most relevance in the academic field. The concepts resulting from this research were:

- Basic Income
- Circular Economy
- Community Banks
- Complementary Currencies
- Degrowth/Post-growth
- Economy for the Common Good
- Ethical Banking/Finance
- Ethical Consumerism
- Fair Trade
- Green Economy
- Local Exchange Trading System
- Microcredit
- Shorter workweek
- Social Business
- Solidarity Economy
- Sufficiency Economy

We then searched these key words through Scopus[2], applying topic and time limitations[3]. As our purpose was to find those proposals that currently result to have most relevance in the academic field, as selection criteria for the study we selected the 10 key words (marked in the table with *) that resulted to have the highest number of publications and that at the same time cover different domains of economics.

Table 1: *Total number of publications per category. Source: The Author*

Key words	N° Publications
Basic Income*	505
Circular Economy*	1521
Community Banks & Ethical Banking/Finance*	256
Complementary Currencies & LETS*	140
Degrowth/Post-growth*	401
Economy for the Common Good	7
Ethical Consumerism	105

[1] Bibliometrics is the scientific analysis of publications that seeks to identify the major fields of study within and across scientific disciplines and the most influential publications, research institutions, and researchers in each of these fields.

[2] We chose Scopus as search engine, as it is "the world's largest abstract and citation database of peer-reviewed literature, [which includes] scientific journals, books and conference proceedings, covering research topics across all scientific and technical disciplines, ranging from medicine and social sciences to arts and humanities", https://www.elsevier.com/solutions/scopus, Retrieved on the 30/06/2018

[3] For a more complete description of the methodology, please refer to the first part of the study: Mapping economic change Part1: a bibliometric analysis of the current state of sustainable economics initiatives. For the research strings used, refer to the annex. The number of publications refers to the 30/06/2018.

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Fair Trade*	1484
Green Economy*	1238
Microcredit*	950
Shorter workweek	27
Social Business*	361
Solidarity Economy*	217
Sufficiency Economy	71

2.1 Qualitative Analysis

To assess our qualitative analysis of the concepts presented, we first reported a short description of each one of them. We based these definitions on specific literature reviews for each key word, acknowledging that the literature review is a complex process, which can be defined as "an interpretation of a selection of published and/or unpublished documents available from various sources on a specific topic that optimally involves summarization, analysis, evaluation, and synthesis of the documents" (Onwuegbuzie et al., 2010, in Onwuegbuzie et al., 2012, p.2). As selection criteria for the literature review, we considered those publications with the highest relevance and clarity in describing and analysing the key word, and the authors which resulted to be the most preeminent in the topic. Moreover, to assure the correctness and commonly shared definition of the concepts, we used a between-source triangulation, which implies to seek convergence and corroboration of information from different source types (Onwuegbuzie et al., 2012).

Secondly, we applied a preliminary classification of all the topics according to three criteria:

The economic domain the key word belongs to (consumption – labour – production - finance/capital - trade);
The type of initiative (bottom-up or top-down);
The scale where the initiative can be implemented (local, national, international).

In this phase we analysed all the key words emerged from the snowballing approach in order to have a broader overview about the distribution and the types of the initiatives.

We then finally focused specifically on the 10 key words selected, and we applied a hermeneutic qualitative analysis to interpret and compare their core conceptualizations. In particular, we created a scheme which orders the key words on two axes: radical-conservative and environmental-social. The first axe shows the closeness of the topic to traditional or alternative economic approaches, whereas the second axe reports whether the focus of the initiative is more towards the ecological or the social field. Moreover, in both this ordering and in the preliminary classification we considered the number of publications: the goal was to find some possible similarities between the key words that have more relevance in the academic field, to find their main characteristics and to understand why and which implications could create their difference in visibility.

3.Results and Discussion

3.1Definition of the concepts

In order to better analyse the concepts previously presented, we will first report a short definition of each one of them based on the literature review.

Basic Income

"A basic income is a periodic cash payment unconditionally delivered to all on an individual basis, without means-test or work requirement. It has the following five characteristics:

1.Periodic: it is paid at regular intervals (for example every month), not as a one-off grant;

2.Cash payment: it is paid in an appropriate medium of exchange, allowing those who receive it to decide what they spend it on. It is not, therefore, paid either in kind (such as food or services) or in vouchers dedicated to a specific use;

3.Individual: it is paid on an individual basis—and not, for instance, to households;
4.Universal: it is paid to all, without means test;
5.Unconditional: it is paid without a requirement to work or to demonstrate willingness-to-work" (Basic Income Earth Network[4]).

Moreover, basic income is not a substitute of welfare, as it just complements services like free education or social security, and is publicly funded, that means it is paid by some public or governmental institution with public resources (Van Parijs, 2004; Wispelaere and Stirton, 2011).

Circular Economy

"A regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops" (Geissdoerfer et al. 2017, p.759). This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling (ibidem). In opposition to the current economic system, which is linear and based on extraction- transformation-use and finally waste of resources, a central theme of the CE concept is the valuation of materials within a closed-looped system, with the aim of lowering the use of natural resource and reduce pollution, avoiding resource constraints and sustaining economic growth. "The principles of the CE concept include the 6Rs (reuse, recycle, redesign, remanufacture, reduce, recover)" (Winans et al., 2017, p.826). Circular Economy is therefore "an industrial economy that is restorative or regenerative by intention and design" (Ellen MacArthur Foundation, 2013b in Geissdoerfer et al., 2017, p.759), which "aims to keep products, components and materials at their highest utility and value, at all times" (Webster, 2015 in ibidem).

Community Banks & Ethical Finance

Community banks (CBs) are institutions that assume "a leading role of promoter of local development, empowerment and community organization when articulating- simultaneously- production, trading financing, and training of the local community" (Melo, 2008 in Vasconcelos Freire, 2013, p.53). "A community bank is owned by the population living together in the same neighbourhood or locality. They are not just owners but, above all, also users of the bank" (Singer, 2013, p.48). Therefore, being both owners and users, these members aim at the economic development of their community. "The purpose of the community bank is not to maximize profit as capitalist banks do, but to foster the economic development of the community where the banks has been created and by which it is used" (ibidem, p.47).

CBs are therefore defined by: 1. Being "not-for-profit; 2. The purpose of the economic initiative is subject to their social purpose (or social utility); 3. They rely on proximity-based relationships; 4. They seek the social or democratic control of the money, affirming themselves as an economic democracy initiative" (Carvalho de França, 2013, p.97).

Community banks play different roles: "a) developers of non-profit experimentation with new socio-productive models and alternative systems of production, trade, employment and credit; b) lender of resources to those for whom the social return is higher rather than to those from whom they can extract the highest financial return; c)

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[4] https://basicincome.org/basic-income/, Retrieved on 08.08.2018

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promoters of financial education and local economic development in accordance with the principles of solidarity economy; d) agents of experimentation with innovative instruments to stimulate creative and solidarity economy; e) suppliers of financial products and services to certain social groups that seems to be poorly served by the market" (Vasconcelos Freire, 2013, p.68).

Regarding more in general Ethical Finance, its goal is to move toward a more eco-system focused economy and to be an active protagonist of its funding. Ethical Banks are based on 6 core principles:

1.Addressing social and ecological challenges;

2.Transparency;

3.Moving beyond standardization;

4.Developing long-lasting relationships with communities;

5.Operating primarily in the real economy and avoiding speculative activities;

6.All these practices are at the core of the business model (MITx[5]).

Complementary Currencies & LETS

"A complementary currency is a type of quasi-monetary exchange medium that is intended to function as a complement to (rather than an alternative to) standard national currencies" (Costanza et al,. 2003, p.3). CCs have been proposed as a means to stimulate local economies, reduce unemployment, and promote cooperative and sustainable community development (ibidem). A complementary currency is therefore "an agreement to use something else than legal tender (i.e. national money) as a medium of exchange, with the purpose to link unmet needs with otherwise unused resources" (Lietaer and Hallsmith, 2006, p.2). Complementary currencies have been designed "to ameliorate many of the main flaws of the current monetary system not by replacing it, but by supplementing it with a system aimed at promoting cooperation at the local community level" (Costanza et al., 2003, p.3). A local exchange trading system (abbreviated LETS) allows people to negotiate the value of their own hours or services. It is a democratically organised, locally initiated, not-for-profit community enterprise, which provides a community information service and records the transactions of the members that exchange goods and services by using a locally created currency (Croall, 1997). According to its defenders, alternative currencies encourage consumers to buy in their own communities instead of outside, foster the circulation of money inside their region, reduce unnecessary imports and avoid high rates of unemployment (Hlebik in Castells, 2017).

Degrowth

"An equitable downscaling of production and consumption that increases human wellbeing and enhances ecological conditions at the local and global level, in the short and long term" (Schneider et al., 2010 in Dittmer, 2013, p.4). The goal of this approach is not zero (or declining) GDP growth, but to reduce and then stabilise material and energy use within ecological limits (Hardt and O'Neill, 2017). The degrowth project is therefore not a narrow call for GDP reduction, but it aims at a profound transformation of society, based on the ideology

[5]Just Money: Banking as if Society Mattered, 11.405x:
https://courses.edx.org/courses/coursev1:MITx+11.405x+1T2018/course/, Retrieved on 30.06.2018

of ecologism, that is a less “anthropo-centric, more frugal, egalitarian, localized, and democratic society” (Dittmer, 2013, p.4).

Degrowth is a multidimensional concept, based on six key sources: “ecology, bioeconomics, critiques of development, democracy, justice, and the meaning of life and well-being “(O’Neill, 2015, p.1215). It derives from a cultural critique of development, which questions the consumer society and its focus on progress, science, and technology, challenging the idea of “development” itself (DeMaria et al., 2013 in O’Neill, 2015). Kallis et al. (2014, in O’Neill, 2015) stress that degrowth is not just about less, but about different. Degrowth “signifies a society with a smaller metabolism, but more importantly, a society with a metabolism which has a different structure and serves new functions” (ibidem, p.1215). These “new functions include sharing, simplicity, conviviality, care, and autonomy, while structures to achieve these functions include cooperatives, work sharing, public money, and the commons” (D'Alisa et al, 2014 in O’Neill, 2015, p.1215).

Fair Trade

“Fair Trade is a trading partnership, based on dialogue, transparency and respect, that seeks greater equity in international trade. It contributes to sustainable development by offering better trading conditions to, and securing the rights of, marginalised producers and workers, especially in the South” (WTFO[6]). Fair Trade Organizations (backed by consumers) are “engaged actively in supporting producers, awareness raising and in campaigning for changes in the rules and practice of conventional international trade” (ibidem). Fair trade is based on three core beliefs: 1. producers have the power to express unity with consumers; 2. the world trade practices that currently exist promote the unequal distribution of wealth between nations; 3. buying products from producers in developing countries at a fair price is a more efficient way of promoting sustainable development than traditional charity and aid (Linton, 2012).

Fair trade is a social movement, whose members advocate for improved social and environmental standards and the payment of higher prices to exporters. The movement focuses in particular on products that are typically exported from the global South to industrialized countries, like handicrafts, coffee, cocoa, wine, sugar, fresh fruit, chocolate, flowers and gold (Moseley, 2008; Brough, 2008).

Green Economy

Green economy is a wider approach that covers a rather broad range of literature and analysis and that unites under “a single banner the entire suite of economic policies and modes of economic analyses of relevance to sustainable development” (UN Secretary-General, 2010 in Brand, 2012, p.28). It has been defined as an economy that improves human well-being and builds social equity while reducing environmental risks and scarcities. It is therefore an economy that is low-carbon, resource efficient, and socially inclusive that aims to sustainable development without degrading the environment (UNEP[7]). According to the International Chamber of Commerce (ICC[8]), green economy is “an economy in which economic growth and environmental responsibility work together in a mutually reinforcing fashion while supporting progress on social development”. It is based on

6 https://wfto.com/fair-trade/definition-fair-trade, Retrieved on 08.08.2018
7 https://www.unenvironment.org/explore-topics/green-economy, Retrieved on 08.08.2018
8 https://web.archive.org/web/20160505222844/, http://www.iccwbo.org/products-and-services/trade-facilitation/green-economy-roadmap/, Retrieved on 08.08.2018

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six main sectors:

- Renewable energy;
- Green buildings;
- Sustainable transport;
- Water management;
- Waste management;
- Land management (Bukart, 2009).

Microcredit

Microcredit is the extension of very small loans (microloans) to impoverished borrowers who typically lack collateral, steady employment, or a verifiable credit history. It is designed to support entrepreneurship and alleviate poverty (Yunus, 2003). Microcredit programs usually have three common characteristics:

They extend credit to the very poor to promote microenterprise activity, which may increase production and consumption activities and in turn change the demand for common pool resources and the technology for their use;

They often focus on women, especially in developing countries;

Microcredit often employs group meetings and group lending techniques, potentially building human capital and strengthening the social capital of the community (Anderson et al., 2002).

"Microfinance Institutions (MFIs) are special financial institutions: they have both a social nature and a for- profit nature" (Gutiérrez-Nieto et al., 2007, p.131).

Social Business

A business created and designed to address a social and/or an environmental problem; a non-loss, non-dividend company financially self-sustainable where profits realized by the business are reinvested in the business itself (or used to start other social businesses), with the aim of increasing social impact (Yunus, 2009). It is based on 7 principles:

1.Business objective is not profit maximization, but to overcome poverty, or one or more problems (such as education, health, technology access, and environment) which threaten people and society;

2.Financial and economic sustainability;
3.Investors get back their investment amount only. No dividends are given beyond investment money;

4.When investment amount is paid back, company profit stays with the company for expansion and improvement;

5.Gender sensitive and environmentally conscious;
6.Workforce gets market wage with better working conditions;
7 Do it with joy (Yunus et al., 2010).

Solidarity Economy

The perception of economics as a complex space of social relations where individuals, communities and organizations create sustenance through different means and with motivations and aspirations that differ from the maximization of the individual profit (Miller, 2006 in Castells, 2017). "The goal is to introduce solidarity, that is, a concern for the common good, in the heart of the economy so that growth leads to social progress and sustainable development, encouraging companies to become socially and ecologically responsible" (D'Orfeuil, 2003, in Dowbor, 2013, p.40).

The main principle of Solidarity Economy is to foster self-management and cooperation amongst producers and consumers, that means to promote a joint construction of supply and demand, decentralizing production, labour and distribution within the territory (Singer 2013). The idea is to stimulate in the locality an integrated circuit of relations (of interchange) involving producers in conjunction with consumers, better known as "prosumers economy', promoting cooperation between local actors. "Regulation occurs though concrete public debates in the associative space, in an exercise of local democracy in which the residents plan and decide on the provision of products or services, on the basis of effective demands they themselves have previously presented" (Carvalho De França, 2013, p.101). Solidarity economy therefore aims to re-establish an interconnection between the socio-economic and the socio-political dimensions (ibidem).

3.2Preliminary analysis

Going through the above-presented definitions, we notice that the majority of the proposals are focused on the flaws of the financial sector. Community Banks, Ethical Finance, Complementary Currencies and Microcredit (and in a certain extend also Solidarity Economy) are all trying to address the problems related with the concentration of wealth and with the difficulties of poor people to have access to credit. Therefore, all these initiatives have at their core a social goal, with the exception of Ethical Banks, which focus are ecological challenges too. However, the economic vision and the type of approach considered to address the financial sector are quite different among these initiatives. We find especially a division between proposals that try to create at a local level new institutions managed directly by the community, and initiatives with a more conservative vision of economics that simply try to modify the targets of the already existing institutions. Community Banks (CBs) and Complementary Currencies belong to the first group, whereas Ethical banks and Microcredit are in the second one. In fact, through the methodology of CBs, each neighbourhood is responsible for managing the bank, thus there is no hierarchical structure within the network and no bank is a franchise or subsidiary of another one (Instituto Palmas, 2013). Moreover, Community Banks organize the poor around small cooperatives and associations of producers and raise awareness about buying locally made products by local business, following therefore the principles of Solidarity Economy. Complementary Currencies share the same goal, that is a more locally based economy that generates jobs and brings economic development to even the poorest neighbourhoods (Lietaer and Hallsmith, 2006), being the physical tool that facilitates these exchanges at a local level. On the other hand, Microcredit created access conditions for millions of people excluded from the banking system, but since its creation in the 1970s, it did not change at all the paradigm of the monetary system itself, keeping the rules of return on capital and interest (Lietaer and Primavera, 2013). Similarly, Ethical Banks are making an effort to ameliorate the goals and the processes used in the credit system, but it is not part of their priorities to change the core rationality behind. Profit is not a dilemma for Microcredit and Ethical Banks, as it is just considered as a tool to finance social (or ecological) issues. In opposition, the primary mission of Community Banks is social profitability, promoting non-profit experimentation that includes communities in solidarity finance: its goal is to ensure access to financial services in a democratic, ethical and solidarity way, giving priority to those excluded from the banking system, and to strengthen human and social capital (Vasconcelos Freire, 2013). In all the cases therefore the low income population is considered as the main costumer, but Community Banks create, within the

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solidarity finance model, financial tools that promote an integrated development of territories (NESOL_USP in Instituto Palmas, 2013), whereas Microcredit's vision aims exclusively at the provision of services and is coherent with neoliberalism (Rankin, 2001).

Another initiative that is connected to Muhammad Yunus, Social Business, results related to the concepts of the capitalist economy too. As Yunus et al. (2010) point out, the social business idea borrows several concepts from the capitalist vision: the re-investment of profit in the business for expansion and improvements, the financial and economic self-sustainability of the project, the presence of initial investors who get back their investment, and so on. In fact, the word "capitalism" is present in the title of several Yunus' books (i.e: Creating a World Without Poverty: Social Business and the Future of Capitalism, 2009; Building Social Business: The New Kind of Capitalism that Serves Humanity's Most Pressing Needs, 2011). Similarly to Microcredit, then, its proposals are close to conservative economic visions and are focused on the local level. However, in the case of Social Business, the action plan relies on a bottom-up approach, as it is based on the self-initiative of individuals that start an enterprise to address social and environmental problems[9]. Therefore, if we consider the economic domains, this proposal is related mainly to production and labour.

Another topic related to labour, but with a completely different approach, is Basic Income. In fact, the goal of Basic Income is to decouple the equation work=subsistence, creating a parallel system where each individual has the right of a minimum amount of money to cover its basic needs besides its job. The focus of this proposals is therefore social, as it is a strategy against both poverty and unemployment (Van Parijs, 2004), with a quite radical economic vision behind. It necessitates however a political willingness and strong institutions able to implement it at a national level, and it is based on a top-down strategy. This proposal is quite related to Shorter Workweek, which aims to reduce the amount of working hours per week of workers (20-21), in order to enable them to have more free time for creative and leisure activities, as well as for the auto-production of goods and services. Both of these proposals are considered inside the Degrowth framework: as we reported in the definition section, Degrowth is a multidimensional concept (O'Neill, 2015), which has probably the most radical vision towards economics, as it negates growth as the essential factor of development and calls for a reduction of production and consumption (and thus labour) in order to stay inside the planetary boundaries.

In fact, Degrowth seems the most comprehensive proposal presented so far, as on one hand it considers several aspects of the economic domains, and on the other hand takes into account both the biophysical and the social accounts (as reported in figure 1).

[9]A proposals that gathers together the principles of the Solidarity Finance and Social business is the Economy For the Common Good, which we found through our snowballing approach but that we didn't consider for the quantitative analysis for the low number of publications about it.

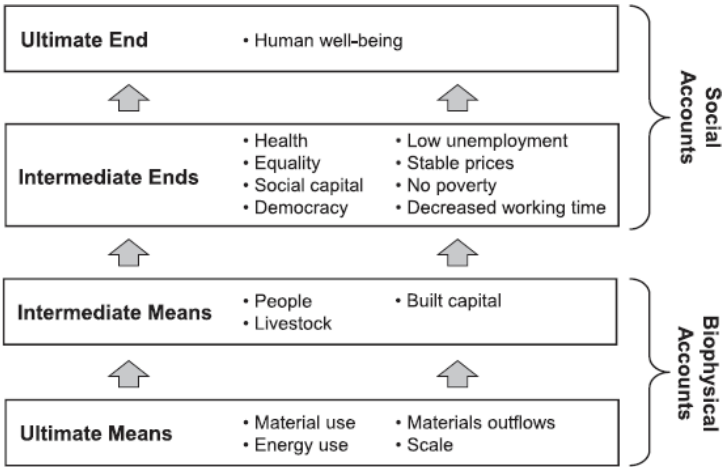

Figure 1: *The indicators in the Degrowth Accounts. Source: O'Neill 2015*

In this perspective, we have both the environmental and social elements, but the biophysical accounts are the basis and the essential requisite on which the social accounts can be built on. Human wellbeing is the ultimate goal (N.B: similarly to the definition we gave of sustainable economics in the theory chapter), it is defined on values that are different from the priorities of the neoclassical economy, and above all it is subordinated to the physical possibilities of the planet.

On the opposite side, we find proposals that are still inside and related to the growth vision of economics: Circular Economy and Green Economy are both relying on technological solutions for addressing environmental challenges. In particular, Green Economy assumes that energy efficiency and new production sectors focused on greener solutions will be able to compensate climate change (Lorek and Spangenberg, 2014), whereas Circular Economy counts on a combination of reduce, reuse and recycle activities. Both of them are focused on the production side, especially on enterprises that need to change their manufacturing processes to lower as much as possible the ecological effects. The social concerns are not considered, as well as no systemic shift are required

(Kirchherr et al., 2017). Moreover, as the focus of Circular and Green Economy are enterprises, besides their geographical position, they are based on a top-down approach at an international level.

To conclude, Fair Trade is the only proposal that is focused on trade. Having the goal of adjust the global market (for some specific goods), it is of course based on the international level and top-down approach too. However, Fair Trade is strongly related to Ethical Consumerism, as the customers have the lobbying power to buy more ethical products and therefore to shift the demand towards them. Fair Trade considers then aspects of human choices that are related not only to rationality, but to values; moreover, it tries to adjust the market, going against the neoliberalist axiom of free market. At the same time, it maintains the division between a producing global South and a consuming global North (Moseley, 2008; Brough, 2008) and does not consider the ecological impact of long-distance exportations (Perna, 1998): we will consider it therefore as medium conservative proposal. Finally, Fair Trade's goal is mainly to secure the rights of marginalised producers and workers, which is a social goal. However, the 5% provision for the community (which is part of the Fair Trade's contracts, Perna, 1998) can be used at a local level for ecological projects too: for this reason we will consider Fair Trade as an initiative with mainly a social concern, but close also to environmental issues.

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3.3Classification and comparison

Based on the previous analysis, we graphically reported the classifications according to the three criteria presented in the methodology chapter.

Table 2 reports the ordering deriving from the division in economic domains:

Table 2: *Classification of key words according to the economic domain. Source: The Author*[10]

	Consumption	Labour	Production	Finance/Capital	Trade
Frameworks	Degrowth & Post-Growth[10]			Solidarity Economy	
		Economy for the Common Good			
Initiatives	Ethical Consumerism	Social Business		Community Banks	Fair Trade
				Ethical Banking	
	Sufficiency Economy	Shorter Workweek	Circular Economy	Complementary Currencies & LETS	
		Basic Income	Green Economy	Microcredit	

As we mentioned in the theory chapter, some of the current proposals refer to more comprehensive and theoretical frameworks, others to initiatives addressing specific issues. As a matter of fact, some of these frameworks comprehend some of the specific proposals: with the use of the colours in the scheme we tried to represent that. For instance, Degrowth comprehends (also) Ethical Consumerism, Shorter Workweek and Basic Income, and therefore they share the same colour. From this first classification we can notice that the initiatives result concentrated in some domains: most proposals regard labour, production and finance/capital, whereas only few focus on consumption and just a couple on trade.We then further reorganized the initiatives according to the second and the third criteria (type and scale); table 3 reports the consequential classification:

Table 3: *Classification of key words according to type and approach. Source: The Author*

	Bottom-up	Top-down
Local	Community Banks Complementary Currencies Local Exchange Trading Systems Social Business Solidarity Economy	Microcredit
National	Sufficiency Economy Degrowth	Basic Income Shorter workweek Economy for the Common Good
International	Ethical Consumerism	Circular Economy Ethical Banking/Finance Fair Trade Green Economy

We can notice two general concentrations: initiatives focused on a local scale are usually based on bottom-up approaches, whereas proposals which operate at an international level require a top-down strategy. However, we recognize that several of these initiatives could belong to more than one category, as many of them are intended

10 Kallis et al. (2012, in Lorek and Spangenberg, 2014) distinguish between three strands of literatures, named “steady-state economics”, “the new economics of prosperity”, and “degrowth”. All of these literatures aim to develop a vision for a prosperous economy that does not rely on economic growth. For simplicity, we will refer to them together as “post-growth” approaches.

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to operate at different levels at the same time and require a mixture of grassroots and institutional intervention. Nevertheless, we decided to create distinctions based on the core aspects of the initiative: for instance, we considered as bottom-up those initiatives that can be implemented directly by citizens, whereas the top-down ones require more sophisticated and organized institutions, like governments, companies or banks that start by themselves the changes required.

We gathered together the results of these three classifications and we applied them specifically to the 10 key words selected. We graphically reorganized them from the one with most publications to the one with the lowest amount, reporting this final ordering with Figure 2:

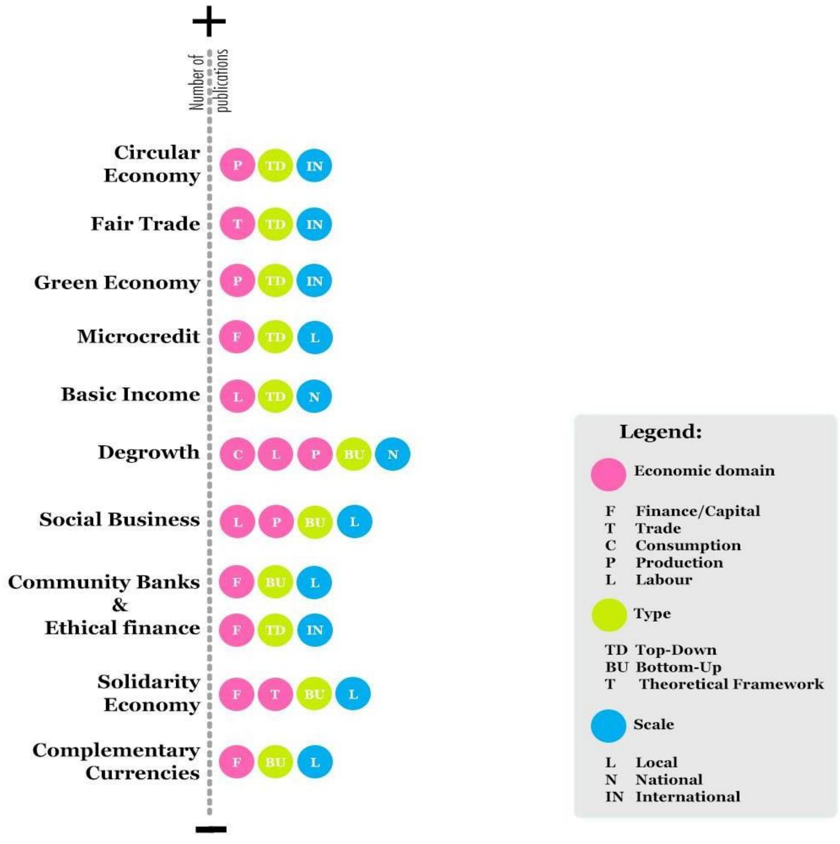

Figure 2: *Classification of key words with number of publications. Source: The Author*

It is interesting to notice that the initiatives that currently have most visibility in the academic field are those that operate at an international level and are based on a top-down approach (Circular Economy, Fair Trade and Green Economy), whereas all the bottom-up proposals are those with the lowest number of publications. Besides Microcredit, initiatives related to the financial domain and working at a local scale are those with the fewest publications. Proposals related to Labour (Social Business, Basic Income and in a certain extent Degrowth) are in the middle.

The next figure reports a classification which disposes key words on two axes: radical-conservative and environmental-social. The first axe shows the closeness of the topic to traditional or alternative economic visions, whereas the second axe reports whether the focus of the initiative is more towards the ecological or the social field.

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Therefore, the vertical position of the key words in the graph represents its closeness to conservative (traditional) or radical (alternative) approaches, whereas the horizontal position signifies its closeness to environmental and/or social concerns (initiatives that are in the middle on the horizontal axes are then concerned both with environmental and social issues). Moreover, the size of the circles represents the amount of publications for each topic: the bigger the circle, the higher the number of publications. The choice for the disposition was made according to the definition and the preliminary analysis previously presented:

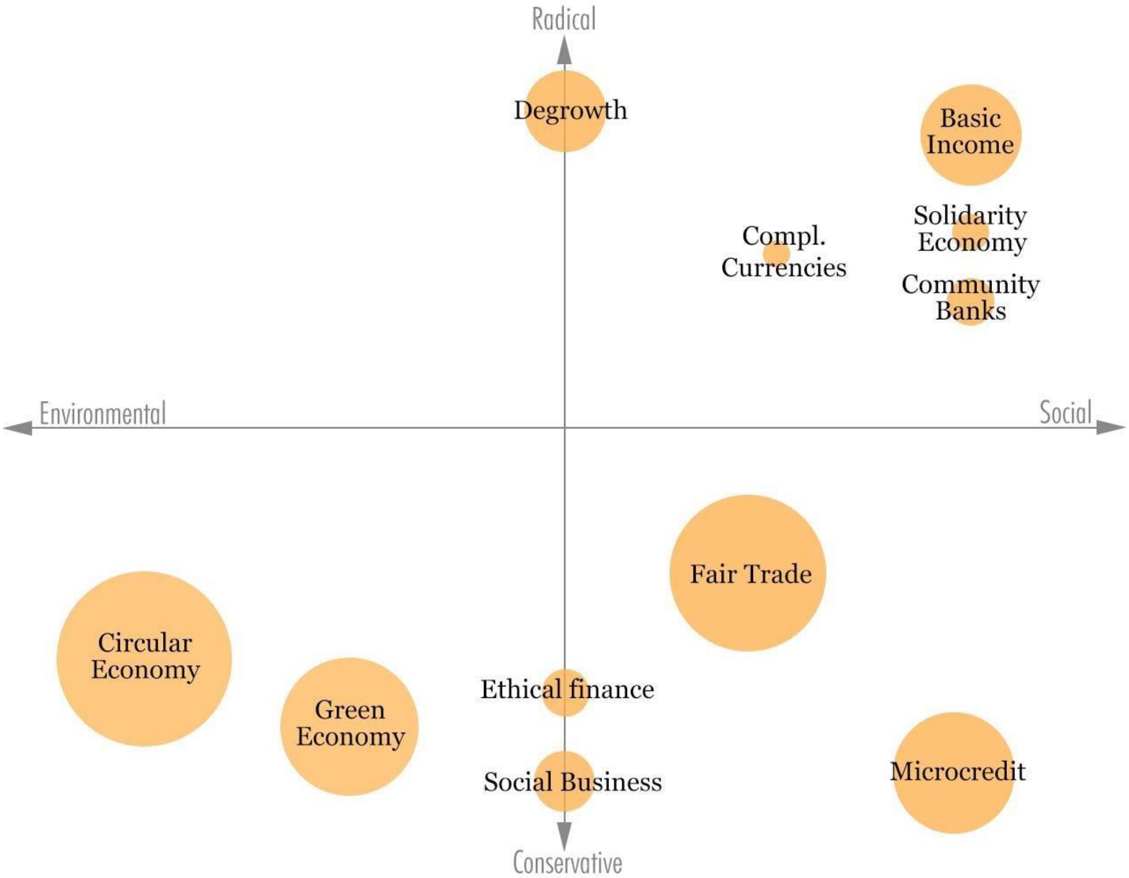

Figure 3: *Concerns and approach of key words with number of publications. Source: The Author*

From this scheme we can notice several trends. First, three initiatives result as concerned both for the environment and the social side, which are Social Business, Ethical Finance and Degrowth, whereas all the other proposals are focused mainly only on one area. Secondly, the initiatives closer to the conservative

approach result to be distributed between the environmental and the social area, whereas all the radical proposals, with the only exception of Degrowth, are related only to social concerns. Finally, the four initiatives with the highest number of publications are close to the conservative approaches; in particular, the proposals with the highest rise in academic visibility in the last 10 years (Circular Economy and Green Economy), are both related to environmental issues and are close to a traditional economic vision. In the discussion section we will further analyse the meaning of this distribution and debate about the possible reasons and implication for these results.

Characterization

According to the qualitative analysis, we can notice several trends in the initiatives that emerged as those with most relevance in the academic field. First, the proposals result focused on some particular domains: production, finance and labour. It seems therefore that the main flaws of the current system are found in these areas, with proposals that are trying to address them. In particular, the initiatives related to production are mainly concerned with environmental issues, whereas those related to labour and finance are more focused on the social side. Therefore, the rationality behind associates the ecological problems with the system of production, and the social inequalities with the financial and working patterns. However, besides many of the proposals are focused on the financial field, most of them have very few publications: the only exception is Microcredit, which actually is not in contradiction with the current paradigm of the monetary system. As Lieater and Primavera notice (in Instituto Palmas 2013), Microcredit simply created access conditions for millions of people excluded from the banking system, but keeps the rules of return on capital and interest. It is therefore close to the conservative economic positions, as all the other proposals with the highest number of publications. Regarding Labour, we can notice two different trends: on one hand we find the attempt to use personal enterprise as a tool to address environmental and social issues (Social Business and Economy for the Common Good), which have nevertheless low visibility in the academic field. On the other hand Labour is conceived as needing a more radical re-conception to be adapted to the new challenges of technologies and Welfare: Basic Income, Degrowth (and Shorter Workweek) are exactly addressing these issues and result to have a discrete visibility in the area. Consumption and trade result thus the fields with less relevance, with the lowest number of proposals, but actually these two areas are strongly related: as already mentioned, Fair Trade is deeply connected with Ethical Consumerism, as it is based on the consumption choices of consumers looking for more ethical products. The narrative behind seems therefore underrating the importance and the effects of the consumption patterns, which however are a key and essential point for shaping the market, and above all to reduce the unnecessary overconsumption that is in fact one of the main issues of the current distorted economic system.

Secondly, we notice that there are mainly two concentrations when considering the scale where the proposals are supposed to be implemented: local/bottom-up and international/top-down. In particular, the initiatives with most visibility are those operating at this latter level, which means at an international scale with a top-down approach. Circular Economy, Fair Trade and Green Economy are all intended to rely on institutions (enterprises, markets, institutes) that can implement them at a supra-national level, whereas on the opposite, bottom-up proposals have very low visibility. It seems therefore that the academia believes that the economic changes necessary for sustainability should come from organized institutions, and not really from grassroots and local movements. This narrative resembles the above-mentioned undervaluation of consumption as a key factor for sustainability, expecting that the necessary changes for improving the economic paradigm should come from institutions instead of individuals.

Thirdly, we notice that most of the proposals are mainly concerned only with environmental or social issues, and those that consider both are exceptions (Social Business, Ethical Finance and Degrowth). It is therefore difficult to find new proposals in sustainable economics which actually have a quite complete and comprehensive vision of the current challenges and that are trying to address them taking in consideration different aspects (the only exception, in the opinion of the author, is Degrowth). In general, most of the radical proposals are related to social issues and have lower publications, whereas the conservative ones are more spread between the two categories and have higher visibility. However, the two initiatives that had the highest growth in the last 10 years (Circular Economy and Green Economy), are both related to environmental issues and are close to an orthodox economic

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vision. It seems therefore that the current concern for economic sustainability in the academic field is concentrated with the

environmental side, and it is not looking for a radical re-conception of the economic paradigm. In fact, as Kirchherr et al. (2017) point out, Circular Economy oftentimes does not mention any systemic shift: its main aim is economic prosperity, followed by environmental quality; its impact on social equity and future generations is barely mentioned.

4. Conclusions

With this research, we reported a high interest of sustainable economics for proposals that are focused on "efficiency" and "green" as solutions for sustainability, as the topics that currently have most visibility in the academic field consider efficiency as the main strategy for sustainability. However, these magic words seem to be used to re-legitimate the system, as they are generally closer to conservative visions of economics. But above all, as we already pointed out in the theorical chapter, they are not sufficient to remain inside the planetary boundaries, as they are based on an *infinite growth* vision. At the same time, efficiency and sufficiency are not incompatible: the first is actually an essential key component of technological innovation, but its effectiveness from a sustainable perspective can be fundamental only inside a greater proposition of reduction of consumptions.

In general, we noticed that the initiatives analysed have some common key aspects: they are not based on an "aid" approach, where we would see some strong countries with pre-packaged solutions that try to impose them to other countries considered as "less developed", creating a dependence that exactly characterized the firsts attempts of international cooperation in the last century. In the cases we considered there is a different approach, more focused on how each territoriality, on different scales, could implement some strategies to address sustainability. We find a general attempt to re-take possession of economics at a local and communitarian level, in certain cases building new or alternative institutions when it is not possible to change the existing ones. Moreover, profit seems to disappear from the goals or at least to be moved to the background, and to be considered as a tool to fund the initiative itself, which has now at his core environmental or social concerns to be solved.

We can conclude therefore that, besides a different approach towards growth which defines in a certain extent the closeness to more conservative or radical visions of economics, the initiatives considered are not in opposition to each other: most of them take into consideration different aspects of economics, and together they

can thus be complementary. We tried to build a possible scheme that unifies these proposals into an integrated plan for a more sustainable economy:

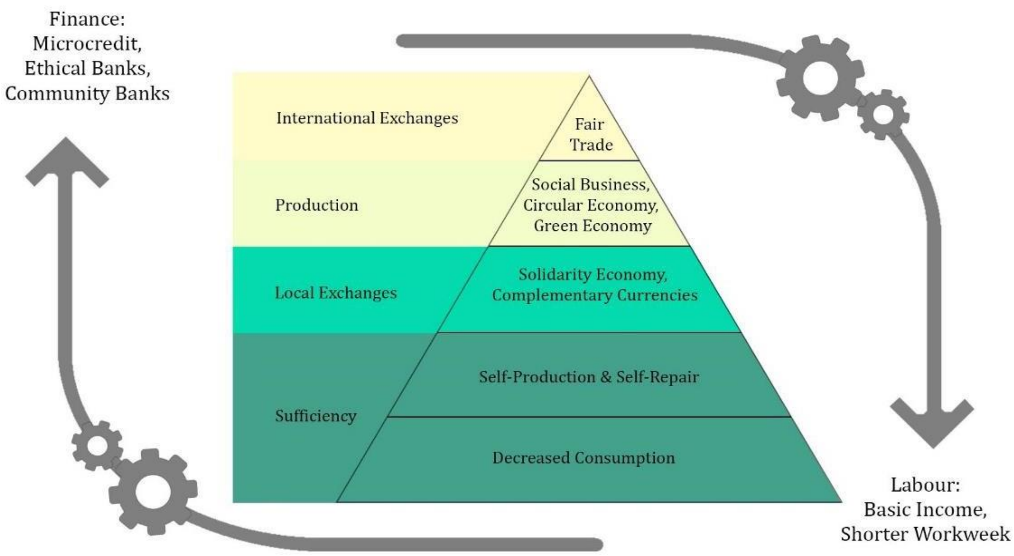

Figure 4*: Integrated proposal of sustainable economics. Source: The Author*

This proposition is based on a hierarchal core (the pyramid) inside a financial and labour framework which makes possible its application (the arrows). The system is founded on a sufficiency vision, which states at the base the importance of decreasing consumptions and to self-produce and self-repair most of the goods and the services. This assumption follows the precepts of Degrowth, with the aim of changing lifestyles towards new habits that allow mankind to remain inside the planetary boundaries. Above, we find the guidelines for exchanges, which should be mostly based on a local level in order to reduce as much as possible the ecological and social effects of long-distance trades. The precepts of Solidarity Economy and the use of Complementary Currencies may help the implementation of this level. Over up, we find (industrial) production, which should follow the goals and processes established by Social Business, Circular Economy and Green Economy. Finally, for each exchange that cannot be solved at a local level, international trade can be based on the principles and rules of Fair Trade.

The financial sector would be the lubricant of this model: banks, working according to the standards of Ethical Banks, could use Microcredit to widen the accessibility to credit of poor people, whereas Community Banks can be created by citizens themselves to control and regulate the distribution of money in their territory. On the other hand, a shorter Workweek and the presence of a Basic Income would help the creation of a different meaning of work, more based on its social utility instead of its capacity to make a living. Overall, from a linguistic perspective, this model aims to *sufficiency* instead of only *efficiency*: to reduce resource consumptions per capita improving at the same time the quality of life (Friends of Earth Europe, 2018).

We believe that presented in this shape, which means as an integrated proposal of sustainable economics, these initiatives can gain more easily visibility, and above all result as more effective and robust in proposing themselves as a practical and independent alternative to the current economic paradigm.

It remains, anyway, the key question about the financial feasibility of the integrated economic model presented, or more in general of any system proposed which is not based on the assumption of an infinite growth. Besides the several counter-arguments which could be used to prove the unfeasibility of the current paradigm, based on externalizing anything which is not making profit, the issue remains: how is it possible to achieve financial stability

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while decreasing consumptions (Hardt and O'Neill, 2017)?

With this study, we are then opening a call for further research about the practical capacity of sustainable economics to be autonomous from the current paradigm, to not depend on forms of financial aid to survive; as a matter of fact, how to self-sustain itself.

Annexes:

Methods:

Research strings:

Basic Income:

TITLE-ABS-KEY ("basic income") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Circular Economy:

TITLE-ABS-KEY ("circular economy") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Community Banks & Ethical Finance:

TITLE-ABS-KEY ("community banks" OR "ethical banking" OR "ethical finance") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT- TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Complementary currencies & LETS:

TITLE-ABS-KEY ("alternative currencies" OR "complementary currencies" OR "local exchange trading system") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Degrowth/Post-growth:

TITLE-ABS-KEY ("degrowth" OR "post-growth") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Economy for the Common Good:

TITLE-ABS-KEY ("economy for the common good") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Ethical Consumerism:

TITLE-ABS-KEY ("etichal consumerism") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR

LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Fair Trade:

TITLE-ABS-KEY ("fair trade") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Green Economy:

TITLE-ABS-KEY ("green economy") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Microcredit:

TITLE-ABS-KEY ("microcredit") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Shorter Workweek:

TITLE-ABS-KEY ("shorter workweek" OR "reduced working hours") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Social Business:

TITLE-ABS-KEY ("social business") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Solidarity Economy:

TITLE-ABS-KEY ("solidarity economy") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

Sufficiency Economy:

TITLE-ABS-KEY ("sufficiency economy") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA , "BUSI ") OR LIMIT-TO (SUBJAREA , "ECON ") OR LIMIT-TO (SUBJAREA , "SOCI ") OR LIMIT-TO (SUBJAREA , "ARTS ") OR LIMIT-TO (SUBJAREA , "ENVI ") OR LIMIT-TO (SUBJAREA , "DECI "))

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Benchmark Analysis For Recycled Glass In Austrian Waste Management

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Abstract

The amendment of the Waste Framework Directive of the European Commission has set a new target for the use of recyclates. It is one of the most significant findings of this strategy that recyclates are currently too infrequently integrated into new products. Glass recycling, however, is widely accepted by the society. The chemical and physical properties of glass enable an almost 100 % rate of recycling. Furthermore, the society is experienced in separating glass by colour, resulting in high-quality recycling glass for the production of new glass. Cullets are significant here. Evidently, the price of recyclates is linked to the price of primary material. Practical experience has shown, however, that pricing also correlates with different quality parameters such as degree of mixing, degree of degradation and presence of impurities.

This paper examines the correlation between different quality features and how they affect the price of cullets. Experts from the Austrian processing and recycling business were interviewed about the most important parameters of their quality inspection and how they affect the pricing policy. Additionally, quality parameters for input and output material are included. Besides the interviews, specific questions on correlations between the price and quality of cullets were e-mailed to several stakeholders in the glass industry.

The main purpose of this paper was to identify the effects of different quality parameters on the pricing policy. Experts from the glass processing industry did not confirm a correlation between price and quality, however: higher quality does not necessarily mean higher prices. Glassworks are ready to pay higher prices for higher qualities in order to meet their sustainability objectives or to expand their production capacities.

Keywords: Recyclates, Cullets, Quality, Price, Correlation

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1.Introduction

Many people would associate glass recycling with a closed and perfectly operating circular economy. The properties of glass enable almost full recovery in recycling processes without any loss of material properties or quality (Aldrian et al., 2018).

Glass is an indispensable part of everyday life, whether in packaging or in any of many other areas. Glass is also highly accepted by our society. In terms of sustainability, glass packaging is often preferred to plastic packaging. The increased recycling rate required by the European Commission's circular economy package, up to 75 % for glass packaging by 2030, is no major challenge for the local waste management as the current recycling rate in Austria is already well above this target (European Commission, 2019)

In contrast to the limited use of plastic recyclates in new products, recycled glass is one of the most important components in producing glass packaging. Today, about 60 % of new container glasses are made of recycled glass. Green container glass even contains up to 90 % of recycled glass (Initiative der Glasrecycler im Aktionsforum Glasverpackung, 2019).

In addition, the use of recycled glass can reduce energy costs and emissions and even help companies act more sustainably. Pursuant to Art. 2 (4) of the Austrian Abfallwirtschaftsgesetz (AWG 2002), glass packaging is classified as waste requiring separate collection. In Austria, about 80,600 containers for both white and stained glass are provided for separate collection (BMNT, 2017).

Using waste glass in container production depends on how aware citizens are of waste separation. The purer waste glass is separated, i. e. the less its colours are mixed by neglect or on purpose, the more cullets may be integrated into new container glass (Aldrian et al., 2018). The need for high quality is evident. Austrian legislation, however, does not stipulate any quality standards for waste glass or minimum requirements for oven-ready cullets.

This paper addresses the quality requirements for waste glass and discusses whether price and quality of this material are correlated. In addition, quality requirements for input material and treated glass as well as minimum requirements for oven-ready cullets are included. The importance of quality control and its implementation is underlined, focussing on container glass like bottles, glass packaging and cosmetics glass fed into separate collection systems. In 2017, the glass industry produced about 420,000 tonnes of container glass, about 239,000 tonnes of which had been collected separated. This collection volume allows glass packaging produced in Austria to include an average of 2/3 of waste glass. Furthermore, the production of glass in Austria mainly concerns packaging glass. At more than 81 %, this sector dominates in numbers (WKO, 2017).

2.Methods

A market analysis of glass cullets was conducted to identify the quality benchmark in glass recyclates, performed by observing the development of pricing, identifying the drivers of the increase or decrease of value and verifying whether this value is related to glass quality or to other economic features.

To analyse the correlation between price and quality, glass processing plants, glassworks, manufacturers of preparation equipment and associations dealing with glass recycling received a specially designed assessment guide. In addition to personal discussions with representatives of the companies listed above, the German glass industry was approached with short and targeted e-mail questions. Altogether, 15 different stakeholders of the glass industry responded. Three phone calls were made, reaching two glassworks and one manufacturer of preparation equipment. In addition, about 30 e-mails were sent to glass-processing plants, glassworks, manufacturers of preparation equipment and glass recycling associations, resulting in a return rate of approx. 45 %. Two glassworks, six glass-processing companies, one manufacturer of preparation equipment and three associations responded. Figure 1 shows the distribution of the consulted companies by stakeholder affiliation in the cullet industry. 40 % of glass processing companies, 27 % of glassworks, 20 % of associations and 13 % of manufacturers of preparation equipment participated in the survey.

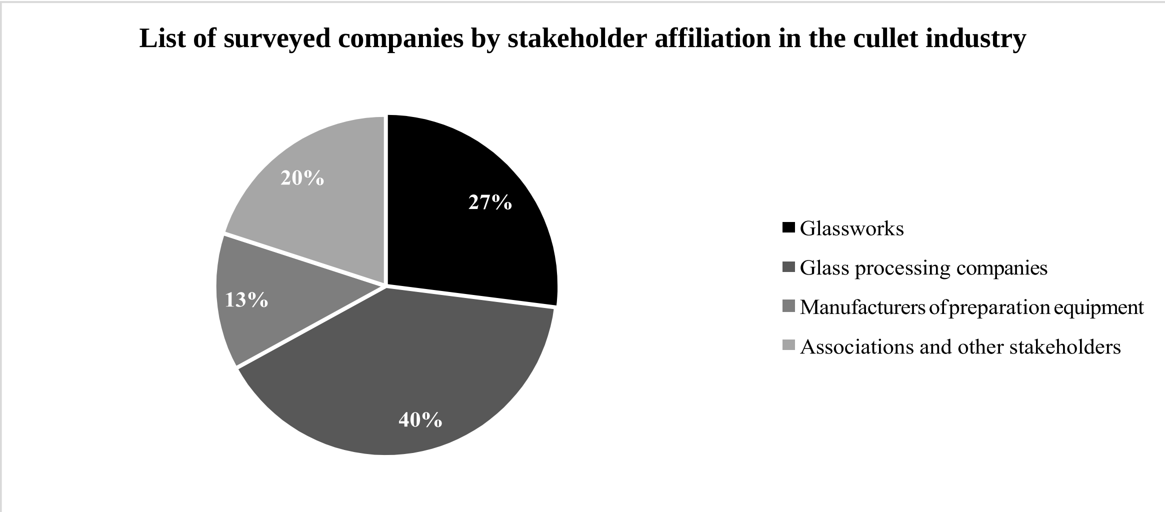

Figure 1. *Surveyed companies by stakeholder affiliation in the cullet industry*

For the telephone interviews, a specific questionnaire was designed to address the correlation between price and quality of waste glass cullets, targeting the following questions:
Which types of waste glass are processed or used?
Is there a way how to assess the composition of input and output flows?
Which contaminants have to be removed and how is waste glass processed? What is the amount of impurities and its upper limit beyond which product quality and cost-effectiveness of the treatment are impaired?
What are the quality requirements for the products and how is quality control performed?
Which developments/trends can be identified and derived in the market for cullets?
Which unexploited potentials are currently identified in the field of waste glass processing and recycling?
How could the quality of the waste glass collection system be improved?

Stakeholders received compressed e-mail editions of the above questions, followed by additional questions or brief telephone calls if any uncertainties or significant new findings occurred.

3.Results and discussion

3.1Quality requirements

Waste glass is indispensable for the production of new container glass. For example, the relative content of waste glass is up to 90 % for green glass and up to 60 % for flint glass (BMNT, 2017). Evidently, such a high recycling rate can only be achieved if the quality is sufficient. In addition, consumers support closed-loop circulation by

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separating waste glass from municipal waste.

Currently, Austrian law does not stipulate any minimum quality specifications for waste glass to be used in the container glass industry or for oven-ready cullets. The Bundesverband Glasindustrie e.V. (BV Glas), the Bundesverband der Deutschen Entsorgungs-, Wasser- und Rohstoffwirtschaft e.V. (BDE) and the Bundesverband Sekundärrohstoffe und Entsorgung e.V. (BVSE) have jointly developed general specifications regarding the quality of waste glass and oven-ready cullets which are observed by all European glassworks. These associations have also tackled waste glass fed to processing plants and developed a technical specification for hollow glass, enforcing standardisation in glass recycling and glass processing. Additional agreements are made between waste glass processors and glassworks generally exacerbating the values defined in the 'Quality requirements for cullets to be used in the container glass industry' guideline T 120 or adding additional parameters. These strict requirements allow the glass industry to produce new products of consistent quality.

Below, the quality requirements for waste glass are described in more detail. Furthermore, the product specifications of hollow glass developed by the associations mentioned above are examined. Finally, the minimum quality specifications for oven-ready cullets are specified. The following descriptions refer to the source 'BDE (2019)' in the References.

3.1.1Product specifications for hollow glass

Since this paper discusses container glass, the product specifications of hollow glass are given first. The following refers to the associations mentioned above. Contaminant limits and purities of the collected fractions are particularly emphasised because a certain purity of the fraction is essential for its use by glassworks. The following product specifications apply:

Product specification of collected hollow glass, type flint glass TR 201 (BVSE & BDE, 2013a)
Product specification of collected hollow glass, type green glass TR 202 (BVSE & BDE, 2013b)
Product specification of collected hollow glass, type amber glass TR 203 (BVSE & BDE, 2013c)
Product specification of collected hollow glass, type stained glass TR 204 (BVSE & BDE, 2013d)

The product specification sheets refer to container glass such as bottles, jars, pharmaceutical and cosmetics glass from glass packaging collection points. A comparison of the listed product specification sheets is shown in table 1.

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Table 1. *Product specifications of hollow glass (BDE, 2019)*

	Flint glass[1]	Green glass[2]	Amber glass[3]	Stained glass[4]
Purity in wt.% Glass according to the specified amounts of contamination with other types of glass	min. 97.00 % max. 1.00 % max. 2.00 %	min. 97.00 % max. 1.00 % max. 2.00 %	min. 97.00 % max. 1.00 % max. 2.00 %	min. 97.00 % max. 1.00 % max. 2.00 %
Amount of other coloured glass	max. 3.00 % *Green*: 1.00 % *Amber*: 2.00 %	max. 15.00 %	max. 15.00 %	max. 10.00 %
Impurities Maximum amount of impurities (max. 1 % in total)				
- Ceramics, stone, porcelain	0.15 %	0.15 %	0.15 %	0.15 %
- Other waste (cans, plastics, cardboards)	0.10 %	0.10 %	0.10 %	0.10 %
Maximum other types of glass (max. 2 % in total)				
- Quartz glass	-	-	-	-
- Borosilicate glass	-	-	-	-
- Glass ceramics	0.01 %	0.01 %	0.01 %	0.01 %
- Glass from electronic equipment	0.005 %	0.005 %	0.005 %	0.005 %
- Lead crystal glass	0.01 %	0.01 %	0.01 %	0.01 %
- Wired glass	0.20 %	0.20 %	0.20 %	0.20 %
- Car glass	0.20 %	0.20 %	0.20 %	0.20 %
- Flat glass	2.00 %	2.00 %	2.00 %	2.00 %
- Ampoules, injection glass	2.00 %	2.00 %	2.00 %	2.00 %

[1] Product specification of collected hollow glass, type flint glass TR 201 (BVSE & BDE, 2013a)
[2] Product specification of collected hollow glass, type green glass TR 202 (BVSE & BDE, 2013b)
[3] Product specification of collected hollow glass, type amber glass TR 203 (BVSE & BDE, 2013c)
[4] Product specification of collected hollow glass, type stained glass TR 204 (BVSE & BDE, 2013d)

3.1.2 Quality requirements for cullets used in the container glass industry

The following refers to the 'Quality requirements for cullets to be used in the container glass industry' guideline T 120 (BV Glas et. al., 2014).

Container glass from households, industry and production such as bottles, jars, pharmaceutical and cosmetics glass (soda-lime glass) are included. The following substances should not be included: lead glass, non-processed safety glass, glass ceramics, lighting glass, TV glass, quartz glass, borosilicate glass, other leaded glasses and all

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substances that may interfere with the melting and production process.

The quality of the processed cullets has to be maintained during transport. For storage and delivery, ensure that the processed cullets are not exposed to contamination, including but not limited to suitably cleaned means of transport (e. g. lorries) and clean collection bins.

Maximum content of impurities

The limits given in table 2 represent monthly averages or averages of at least 250 tons of glass which should not be exceeded. All values are upper limits. Limits refer to flint, green, amber and stained container glass, respectively.

Table 2. *Maximum content of impurities (BDE, 2019)*

Ceramics, stone, porcelain	20.0 g
Non-ferrous metals	3.0 g
Ferrous metals	2.0 g
Glass ceramics > 10 mm	5.0 g
Glass ceramics ≤ 10 mm	10.0 g
Loose organics	300.0 g
Moisture	2.0
Heavy metals (Pb, Cd, Cr(VI), Hg) (considered as guideline)	200.00 pp

Ceramics, stone, porcelain (CSP)

Ceramics included in the melt may react explosively. Therefore, a high CSP value should be avoided. The melting tank and process are very sensitive and precisely tailored to the mixture, fed via special feeding systems. Each tank is customised and adjusted to the requirements of the glassworks. Due to their higher melting point, ceramics, stones and porcelain do not completely melt in the tank, however, and remain in the processed glass, creating inclusions.

These inclusions may cause breaking, defects and/or deformation of container glass. First, they are visible defects causing rejection of the finished product. Therefore, the amount of reject increases at what is called the ‘cold end’ where each glass product is precisely measured and checked for defects using special inspection systems. If a defect is not detected, it may break at the bottler’s, during transport or even at the end-consumer’s. With carbonated beverages, risk of breakage is particularly high (e. g. champagne bottles). Thus, inclusions can be a safety-related defect since their degree of hardness will differ from that of glass, resulting in voltage differences which may ultimately cause the glass to burst.

Metals (ferrous and non-ferrous)

Metals with high melting temperatures (1,500 - 1,600 °C) are difficult to melt. Long-term damage of the melting tanks is the result as the metals sink to the bottom of the tank and rotate there due to the flow of the refractory material. Damage to the bottom of the melting furnace may also be due to metals melting at lower temperatures, such as lead. Metals that are also hydrophobic to the refractory material, such as ferrous metals, may aggregate into a ball which can lead to a rotational movement caused by the holes in the bottom of the tank. Metal-stopping layers are used to prevent this kind of damage.

Loose organics

In general, loose organics cause carbon input. The mere presence of carbon is basically not a problem but different contents of carbon may constitute one. If the difference is too great, colours may begin to drift, causing large- scale production losses or deviations from the colour specifications of the customers. Carbon triggers an oxidative process in the melt that may cause the colour of the glass to change, especially with flint glass that may then be tainted grey or yellow. On the other hand, excessive or irregular accumulation of organics on the surface of the melt may cause foaming or blistering. When the molten material is surface-fired, too little heat is induced by the foam barrier. The result is irregular melting, higher energy input and/or longer residence times of the material in the melting tank. In extreme cases, nests from slightly molten glass material may arise.

The limits set to loose organics have several arguments. For energetic and environmental reasons, melting tanks are now operated with very small excessive air. Organic content influences this residual oxygen content. In practical application, therefore, recycled waste glass is stored for about six weeks before it is mixed with molten glass, to avoid any influence of organics (fermentation).

Loose organics have a tendency of fine pieces of broken glass adhering to them. Due to their high organic content, these fine shards often cannot be completely used as secondary raw materials so that the recycling rate for waste glass will fall short of 100 % (Aldrian et. al., 2018).

Moisture

Moisture is of particular importance for the sorting and preparation of waste glass. If the moisture content is too high, the cullets are difficult to screen and the quality of sensor-based sorting will suffer. As a result, constant transport speed on slides can no longer be guaranteed. If a cullet is slowed down during the sliding process by a ‘sticky’ water film on the chute in the detection unit, it can no longer be blown away by compressed air in the separator on time.

The limit to moisture is set to avoid excessive variations. For the treatment process, a certain amount of moisture is beneficial in preventing dusting and segregation. However, this moisture must be evaporated and therefore should be kept at a minimum

Heavy metals

Since glass can be melted again and again, there is still a lot of ‘vintage’ glass participating in the circulation, melted before lead-sorting equipment had been installed. This ‘vintage’ glass still contains a lot of lead which is slowly reduced by dilution processes. Lead was once used to increase the gloss of the glass (up to 35 % of lead oxide (PbO)). During melting, evaporation in correlation with environmental limits may be significant. However, exceptions are sometimes made to permit higher emission limits. Heavy metals basically do not affect material

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properties or consistency.

This limit is rather politically motivated, driven by the limitation to heavy metals established in the plastics industry. In fact, there is no elution from glass but consumers prefer glass without heavy metals. Of course, increasing accumulation of heavy metals in glass containers is undesirable. For example, basic contaminations of approx. 200 ppm of lead oxide (PbO) are already present in new bottles imported from Asia. In addition, the glassworks are subject to legal stipulations not to be violated by the use of recycling cullets. For example, Art. 4 of the Austrian Verpackungsverordnung of 2014 states that packaging with a concentration exceeding 100 ppm by weight of lead, cadmium, mercury and chromium (VI) is prohibited unless lead crystal is concerned (Verpackungsverordnung, 2014).

Additional parameters

Lead-containing materials

Experts from waste-glass processing have supported these restrictions with additional values. For the discharge of lead-containing materials, a lot of equipment is already installed. Cullets containing lead oxide are detected by optoelectronic devices, such as UV cameras.

Heat-resistant glass

If the ember stream is contaminated with heat-resistant glass, it cannot be cut by the cutter. The reason is that finished conditioned glass is shaped into gobs by the feeder machine and cut by a scissors mechanism at the end of the drop-forming process. If larger melting relics – pieces of CSP or refractory materials - should occur here, the droplet cannot be properly cut, disrupting the production process. Heat-resistant glass and glass ceramics are hard to detect at the input controls of glassworks, requiring appropriate sorting equipment in waste-glass processing. Glassworks and waste-glass processors are well equipped with sorting units detecting and separating heat-resistant glass.

A limit value for heat-resistant glass is given in the specification sheet 'T120' under the item 'Glass-ceramic'. A separation quality of at least 90 % on the part of the system manufacturer is required to avoid the presence of these materials in the ember stream. Most European glassworks tolerate a maximum concentration of 25 g/t of refractory cullets in the ready-to-melt product.

Content of other coloured glass (incoming)

The colour is determined in the grain band > 8 mm square mesh. The maximum contents of other colours for the glass types flint, green, amber and stained are listed in table 3.

Table 3. *Maximum contents of other colours for specific glass types (BDE, 2019)*

	Flint glass[1]	Green glass[2]	Amber glass[3]	Stained glass
Colour amber	≤ 0.3 %	max. 10.0 %	min. 80.0 %	min. 80.0 %
Colour green	≤ 0.2 %	min. 75.0 %	max. 10.0 %	min. 80.0 %
Other colours	≤ 0.2 %	-	-	-

[1] Transition colours from white to green, acid-green and half-white, are white.
[2] All shades of green including the reduced shades of green are considered green. Cullets in the range of 568 nm to 573 nm are considered reduced green hues.
[3] All shades of amber are considered amber.

Requirement for oven-ready cullets

The minimum quality specification for oven-ready cullets is based on the 'Minimum quality specification of oven-ready cullets' guideline TR 310 (BVSE & BDE, 2013e).

Container glass from households, trade and production is considered. The processing plant must be operated with appropriate technology for sorting out contaminants to comply with the quality criteria of oven-ready cullets as defined in table 4.

Requirements for oven-ready cullets

Table 4. *Requirements for oven-ready cullets (BDE, 2019)*

Ferrous metals	≤ 50 ppm
Non-ferrous metals	≤ 60 ppm
Inorganic non-metallic, non-glass materials like ceramics, stones, porcelain or pyroceramics: - cullets > 1 mm - cullets ≤ 1 mm	≤ 100 ppm ≤ 1.500 ppm
Organic impurities like paper, rubber, plastics, fabric or wood	< 2.000 ppm

3.2Quality control

Quality requirements for separately collected waste glass have already been mentioned in the previous section. The industry complies with the guidelines of the Bundesverband Glasindustrie e.V. (BV Glas), the Bundesverband der Deutschen Entsorgungs-, Wasser- und Rohstoffwirtschaft e.V. (BDE) and the Bundesverband Sekundärrohstoffe und Entsorgung e.V. (BVSE) since there are no uniform quality standards. The parameters CSP

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(ceramics, stones, porcelain), ferrous and non-ferrous metals as well as heat-resistant glasses are essential when assessing the quality of cullets. As these materials have different melting temperatures than glass, they do not (completely) melt in the melting tank, causing inclusions and, hence, production problems. In addition to these parameters, the content of lead-containing glass, the organic content and the fine-grain content are important for assessing the quality of the cullet.

Input material is visually controlled by material acceptance staff. Based on their experience, the quality of the glass fragments can be assessed by visual inspection. Attention is paid to the load of undesired impurities such as residual waste, wood and CSP. In case of suspicion, lead glass is checked with an ultraviolet lamp. Quality control in laboratories is not an option for real input quantities, owing to the high amounts passing per day. Hollow glass usually derives from colour-separated collection. The main focus is on the degree of refraction of the cullets and contamination of the loading surface by subcharge, such as gravel. An essential part of input control is the colour distribution of the bulk material since mono-coloured waste glass is a much better secondary raw material than multi-coloured glass. (BVSE, 2019). Stained glass would lead to discoloration (BMNT, 2017). In addition, empirical data show that waste glass fractions in certain regions (for example, in large cities) have a lower quality.

Basically, the following stages of quality control are conceivable after the processing of waste glass:

1.The plant operator trusts his plant and no quality control is performed.
2.There is a continuous sampling in the output stream of the treatment plant. The following parameters are checked in the laboratory:

- colour purity,
- impurities and
- chemical composition.

3.Semi-automated sampling is performed. Continuously sampled material enters an analyser running semi-automated analyses or protocols. A plausibility check made by laboratory staff is not rendered obsolete that way. Quality control by sensor-based machines is still rarely met, though demand by industry is rising.

3.3 Sampling of recycled glass

Sampling may be performed before delivery of the cullets but there are also samples sent by the supplier. Consequently, a 'lot' is built to be analysed, i. e. a typical sample volume taken from a total amount. If the sample volume complies with stipulated limits, the total amount will be delivered. No further sampling is then required upon receiving the goods, and time is saved. The Bundesverband Sekundärrohstoffe und Entsorgung e.V. (BVSE) and the Bundesverband der Deutschen Entsorgungs-, Wasser- und Rohstoffwirtschaft e.V. (BDE) have jointly developed a guideline for standardised sampling of cullets to ensure reproducible measurement results: 'Sampling for the use in the container glass industry' TR 101 (BVSE & BDE, 2013f).

3.4 Market study

Pricing structure

The market price for waste glass is primarily based on geographic conditions. The following questions are

significant: Where does the cullet come from? Where does the cullet go to? Furthermore, the market price includes collection, processing and transport and is based on the primary raw material and the amount of energy consumed by processing. There are no parameters defining the purity of waste glass.
The following factors are essential:

Price for quartz sand/soda/lime,
transport of the cullets to the treatment plant,
treatment efforts,
energy drawback from using primary raw materials in the melt and
transport of cullets to the glassworks.
Usually, the glassworks negotiate prices with the suppliers 'delivered to the delivery point' so that the material price for waste glass will vary with the site of the processing plant and the distance to the glassworks. The prices presented in table 5 are currently observed in Austria (recycled waste glass).

Table 5. *Prices for recycled cullets (BDE, 2019)*

Glass type	Price range	Price variation
Flint glass	€ 85,- to 90,-/t	+/- € 10,-/t
Amber glass	€ 85,- to 90,-/t	+/- € 10,-/t
Green glass	€ 65,- to 70,-/t	+/- € 10,-/t
Stained glass	€ 40,- to 50,-/t	+/- € 5,-/t

Container-glass processing experts have claimed that prices indicated in the table above are currently tolerable. They mentioned, however, that the pricing may also turn unfavourable; for example, the price for a tonne of waste glass may drop to € 20,-. The experts agreed on the other hand that any price above € 100,-/t was hard to achieve. Moreover, prices for waste glass are generally declining due to decreasing expenses for energy investments into production.
Observations in Germany show that the price of waste glass can vary due to geographical conditions. In the south there is an excess of white glass but fewer glassworks are established. In the north there are many glassworks and a high demand for white glass. Therefore, the price of white glass is higher in northern Germany than in the south. Prices for green glass are distributed exactly the other way round: In the north, there is an excess of green glass, in the south there is a great demand for it. One reason for this discrepancy may be found in the brewing industry located in Bavaria. Hence, the price of green glass is higher in southern Germany than in the north.
Correlation: price and quality
Quality does not really affect pricing policies. All suppliers face the same specifications (usually 'Quality requirements for cullets to be used in the container glass industry' T 120). This quality must be achieved in any

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case. Basically, higher quality of the input material does not result in a higher price: a delivery of qualities below the specified limit values is accepted but not separately priced. Exceeding the limits will cause rejection of the delivery. Waste glass recyclers will pay more for waste glass that is less contaminated because subsequent treatment will be less expensive. However, the main part of recycled waste glass from licensed collection systems is paid a standard price.

<u>The surveyed companies observe the following relationships between price and quality:</u>

One is described like this: If the glassworks expands its processing and requires more waste glass, it is likely to pay a better price.
Another is described like this: Companies are endeavouring to use cullets to produce new glass. Their sustainability strategies pursue the goal of using a high relative amount of waste glass in their new production. The purer the cullets, the more of them can be added to the melt. The higher the amount of cullets, the lower the impact on the environment.
In Austria, prices for waste glass are subject to supply and demand as in the general market mechanism. Higher quality does not need to be more expensive. Occasionally, special glassworks producing cosmetics glass or high-quality bottles will pay higher prices for clear glass. In general, however, prices for cullets have reached a point at which the use of primary raw materials may become economically feasible again.

3.5. Quality benchmark in glass recycling

Market analysis did not provide any information on a benchmark for cullets. Producers of waste glass were therefore asked to identify one. For input materials, the quality standard used by the industry is the 'Quality requirements for cullets to be used in the container glass industry' guideline T 120. Besides, the Bundesverband Glasindustrie e.V. (BV Glas), the Bundesverband der Deutschen Entsorgungs-, Wasser- und Rohstoffwirtschafte.V. (BDE) and the Bundesverband Sekundärrohstoffe und Entsorgung e.V. (BVSE) have jointly developed general specifications regarding the quality of waste glass and oven-ready cullets. These specifications are observed by all European glassworks.

4. Conclusions

Whether there is a correlation between price and quality of waste glass has to be doubted. Experts from the container glass industry do not perceive an interaction of these two parameters. A higher price for waste glass of higher quality will be paid if a company intends to use a high content of cullets in production to achieve sustainability or higher capacity. The price of waste glass emerges primarily from the equilibrium of supply and demand on the general market. Furthermore, the costs for collecting waste glass, processing cullets and transporting to the glassworks enter calculations. Waste glass is priced based on the price of primary raw materials and energy consumption during processing. The market price for waste glass also varies by location of the processing plant and distance to the glassworks.
Quality inspection of waste glass is usually executed by material acceptance staff. Based on empirical values, reliable assessment of the quality of delivered glass waste can be expected. This assessment is compelling for further processing. The parameters 'CSP' (ceramics, stones, porcelain), ferrous and non-ferrous metals as well as heat-resistant glass severely impact the quality of cullets. In addition to these parameters, staff considers the

content of lead-containing glass, organics content and fine-grain content when assessing the quality of waste glass. Currently, there is no minimum quality stipulated in Austria for waste glass applied by the container glass industry or for oven-ready cullets. The Bundesverband Glasindustrie e.V. (BV Glas), the Bundesverband der Deutschen Entsorgungs-, Wasser- und Rohstoffwirtschaft e.V. (BDE) and the Bundesverband Sekundärrohstoffe und Entsorgung e.V. (BVSE) have jointly developed general specifications regarding the quality of waste glass and oven-ready cullets. These specifications are observed by all European glassworks. Their purpose was a standardisation of quality requirements in glass recycling and glass processing. These requirements enable the glass industry to produce new products of consistent quality.

Finally, the use of waste glass in container glass production can be called essential and this material is called the most important raw material for new production. Waste glass processors, manufacturers of preparation equipment and glassworks have invested much effort in recent years into pushing the use of waste glass. Citizens, however, decide by their readiness to separate types of waste glass whether high-quality container glass can be produced from recycled waste glass.

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Data-driven decision making for the acceleration of the Circular Economy

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Abstract

Data science and the circular economy (CE) are two key issues for future business competitiveness. Data-driven decision-making (DDDM) provides new insights into consumer behaviour and material flows across the supply chain thereby enabling circularity strategies such as end-of-life collection, refurbishment, remanufacturing and recycling. However, companies are currently seeking for strategies to unlock the full potential of DDDM for circular strategies. This is mostly because empirical research that integrates the development of circular strategies with the use of data from a business perspective remains almost inexistent. This paper fills this gap by looking into how product and service-related data informs the decision-making process to build circular business strategies in the Dutch industrial sector. This paper makes three major contributions, namely: (i) it develops a new analytical framework bridging the literature on DDDM, CE and systems theory which is useful for strategy development in all fields; (ii) it offers new empirical evidence on how companies use DDDM to foster the transition towards a CE; (iii) it sheds new light into policy mechanisms capable of optimising the interface between DDDM and CE in the manufacturing sector. Our exploratory research reveals a link between DDDM and circular strategy development, which resulted in four types of relationships. The relationships show that data and technologies are a critical enabler for the acceleration of the CE. Furthermore, variations across companies were observed in the steps of DDDM and the challenges. Lastly, factors on product, process and value chain level are unveiled that influence DDDM. This research offers new perspectives to understand the connection between DDDM and CE from a system perspective and shapes the base for practitioners and academics, who are interested in additional research on the phenomenon, and for policymakers, who are cable of optimising the interface between DDDM and CE in the manufacturing sector.

Keywords: Circular Economy, Data-Driven Decision-Making, Information Theory, Industry 4.0, Strategy Design

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1.Introduction

Manufacturing companies around the world are confronted with the pressure of environmental legislations and increasing price volatility of resources (Lieder & Rashid, 2016). These challenges and limitations of the traditional take-make-dispose economy push manufacturing companies towards more sustainable business decisions. Circular Economy (CE) is gaining attention as a solution. The CE is an "economic system that replaces the 'end- of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes." (Kirchherr et al., 2017, p. 229). The advantages of these circular approaches are substantial as companies progressively achieve economic and competitive benefits, such as cost reductions or increased profits (Lieder & Rashid, 2016). However, our current economic model is still experiencing an upward trend in resource extraction and greenhouse emissions (Circle Economy, 2019). According to the latest Circularity Gap Report 2019 the world is only 9% circular and the trend is negative (Circle Economy, 2019). It becomes clear that there is an urgent need to use new approaches and solutions to accelerate the transition towards the CE.

The additional value of the CE can be unlocked by pairing circular economy principles with the digital revolution (Despeisse et al., 2017; Geng & Doberstein, 2008). Companies are increasingly making the first step towards data-driven decision-making (DDDM), since it is no longer usual to simply use gut feelings or intuition as the basis for strategic decisions (Mandinach, 2012; Hedgebeth, 2007). Previous studies have shown that more precise and accurate information facilitates the decision-making process leading to higher firm performance (Brynjolfsson et al., 2011; Davenport & Harris, 2007; Loveman, 2003). The majority of the high-performing businesses apply data and data analytics strategically in their daily operations (Davenport & Harris, 2007). Previous studies show that DDDM can lead to a 5-6% increase in a company output and productivity. Positive effects appeared also on measures, such as asset utilization, return on equity and market value (Brynjolfsson et al., 2011). Despite of these positive effects, companies are currently not unlocking the full potential of DDDM to foster circular strategies (Antikainen et al., 2018). There is limited research that integrates the development of circular strategies with the use of data in decision-making from a business perspective (Pagoropoulos et al., 2017; Okorie et al., 2018; Okorie et al., 2017).

Building on this literature gap, this research aims to answer the following research question: How does data-driven decision-making foster Circular Economy strategy development in manufacturing companies? To illustrate the range of applications, this research looks at different industries in the manufacturing sector. This paper makes three major contributions, namely: (i) it develops a new analytical framework bridging the literature on DDDM, CE and systems theory, which is useful for strategy development in all fields; (ii) it offers new empirical evidence on how companies use DDDM to foster the transition towards a CE; (iii) it sheds new light into policy mechanisms capable of optimising the interface between DDDM and CE in the manufacturing sector. The paper is organised as follows: section 2 highlights conceptual features and presents the analytical framework that bridges the literature on DDDM, CE and systems theory. Section 3 introduces the methodology, while section 4 reveals the results derived from the research and discusses policy mechanisms. Finally, section 5 concludes by examining paths for future research.

2.Data-driven decision-making and the circular economy

Since the mid-1990s, the strategic decision-making process in organisations has increasingly gained attention. This process is crucial because it involves those fundamental decisions which shape the course of the organisation (Eisenhardt & Zbaracki, 1992). Currently, companies are incorporating more decisions that decrease their environmental impact while maintaining economic growth (Robèrt et al., 2002). However, it remains unclear in what specific ways companies are fostering DDDM to accelerate the CE. The CE can be considered as a solution to balance ambitions for economic growth and environmental protection (Lieder & Rashid, 2016). It is an economic system in which the value of post-consumption products, resources and packaging is recaptured by exchanging linear material and energy flows with circularity through closed loop production and consumption systems (Jabbour et al., 2017). A circular strategy can be defined as a plan of action designed to accelerate the CE, which involves a highly situated context with particular competitors, customers, suppliers and market changes (Seddon & Lewis, 2003). Circular strategies can be summarized by the ReSOLVE framework of the Ellen MacArthur Foundation (Lewandowski, 2016; Ellen MacArthur Foundation, 2015a). The ReSOLVE framework represents six circular strategies, that are often used to guide organisations in the transition to a CE: Regenerate, Share, Optimise, Loop, Virtualise and Exchange (Lewandowski, 2016; Jabbour et al., 2017; Ellen MacArthur Foundation, 2015a).

Strategic decision-making to increase business circularity can be a comprehensive process. One of the most influential researchers in the field of information processing and strategic decision-making in organisations was Herbert Simon (1960). According to his model on decision-making, the process consists of three distinct steps: intelligence, design and choice (Simon, 1960). Huber (1980) further developed the decision-making model of Simon (1960), by adding the implementation and monitoring steps (table 1).

***Table 1**. Description of the strategic decision-making steps (derived from Simon, 1960 and Huber, 1980).*

Intelligence	Design	Choice	Implementation	Monitoring
A specific problem or opportunity is being identified by the decision maker.	In this step the solution outlines of the problem or opportunity are developed through the use of data and technologies.	In the choice step the possible solutions are compared against each other and the most suitable solution is chosen.	The chosen decision is implemented, through the use of resources such as time, costs and manpower to produce the desired result.	During this step it is ensured that the results agree with those expected at the time the decision was made.

During the strategic decision-making process as described by Simon (1960) and Huber (1980), data and technologies may be used to optimise strategy development. According to Gorry & Morton (1971) decisions can be classified into three types: (i) structured, in which all procedures of each process step are well defined and the data is quantifiable; (ii) semi-structured, in which one of the decision-making steps is ill-structured and not all the data is quantifiable; and (iii) unstructured, in which there are no procedures to act on and none of the data is quantifiable. Most complex business problems and opportunities involve type II and III decisions (Gorry & Morton, 1971). The information processing view by Galbraith (1974) proposes that the more complex a task or decision is, the greater the amount of information needs to be processed in order to achieve a given

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performance level. There are two general strategies to cope with the increasing information need: (i) Companies can reduce the amount of information that is processed; or (ii) Companies can increase its capacity to handle more information. The latest literature on information technologies and tools have recognized that technologies are used to support, enable and improve the efficiency and effectiveness of the DDDM process (Hazen et al., 2016; Brynjolfsson & McElheran, 2016; Stanek et al., 2004; Hedgebeth, 2007). Digital technologies are defined as "electronic tools, systems, devices and resources that generate, store or process data" (Okori et al., 2018, p. 18). There are complex interactions between data and technology use. Technology tools influence the data available and the types of data influence the technology tools for use (Ikemoto & Marsh, 2007). Hazen et al. (2016) recommend to view the different technologies and tools from an integrative perspective, where it is one of many tools that enhances existing organisation-wide business processes and enables new strategic development.

2.1 System approach in DDDM for CE

The strategic decision-making model of Simon (1960) and Huber (1980) represents only a partial approach of the dynamic and complex process of strategic decision-making. Data collection, processing and use in a decision- making process is not done within a single organisation, but through partnerships and collaboration (Mandinach et al., 2006). The model of Simon (1960) and Huber (1980) neglects the complex, embedded and dynamic environment of organisations. A systems approach is proposed that considers three system levels on which strategic decision-making is shaped and information is collected (table 2). The closer the decision maker is to the system level, the more instructional validity the decisions have due to the proximity to the information and the ability to transform the information into actionable knowledge (Mandinach et al., 2006). Even though decision- making and information collection is embedded within a particular level, there will likely be interactions across the levels (Mandinach et al., 2006).

Table 2. *System levels in which DDDM is embedded*

Product level	The product level is focused on shifting linear products to a closed loop design (Jawahir et al., 2015). For example, companies use information on the product's location during the end-of-life phase to choose the right end-of-life strategy.
Process level	The process level is focused on optimising production processes and developing process planning to reduce energy and waste streams without compromising the product's quality or the company's productivity (Jawahir et al., 2015).
Value chain level	The value chain level is taking into account the aspects of the entire value chain, such as the stakeholders and processes involved in pre-manufacturing, manufacturing, use and post use (Jawahir et al., 2015).

Besides research on the value of data and information technologies on strategy decision-making, several other prior studies have demonstrated a relationship between business related factors and DDDM (Zammuto et al., 2007; Papadakis et al., 1998; Brynjolfsson & McElheran, 2016). Zammuto et al. (2007) reveal that increased firm performance can be explained by complementary investments in organisational factors on different system levels. There are several factors that influence and are influenced by DDDM (table 3)

Table 3. *Factors on system levels influencing and influenced by DDDM*

Product life cycle stages	**Product level:** The position of the product in its life cycle determines the type of data that needs to be collected and analysed, and the type of strategy that can be implemented (Zhang et al., 2017). Strategy decision-making on product level can be done within different stages of the product's life cycle: (i) Beginning of Life (BOL), which includes the product design and manufacturing (ii) Middle of Life (MOL), which includes the use, service and maintenance; and (iii) End of Life (EOL), which includes the disassembly, remanufacturing, recycling, reusing or disposing of the product (Zhang et al., 2017).
Firm size	**Process level**: Measured as a firm's total number of employees (Brynjolfsson & McElheran, 2016). Brynjolfsson & McElheran (2016) show that the scale of the firm's operation has a positive influence on the effectiveness and efficiency of the DDDM process. Papadakis et al. (1998) reported that a larger firm size is associated with increased comprehensiveness of the strategic decision-making process. Therefore, smaller firms perform better with a simple, non-hierarchical decision-making structure (Thompson & Bates, 1957).
Educational level of employees	Brynjolfsson & McElheran (2016) reveal that companies with a higher percentage of high educated workers, also have higher levels of DDDM. Hence, effective data use strongly depends on higher education levels (Brynjolfsson & McElheran, 2016). However, digitalisation and automated processes can substitute many jobs, including processes and jobs for which high educated employees are currently needed (Loebbecke & Picot, 2015).
Organisational structure	The distribution of the decision rights in the organisation results in improved efficiency in the decision-making process (Zammuto et al., 2007; Brynjolfsson & McElheran, 2016). The increasing use of DDDM has resulted in emerging cross-location teams within companies, and traditional hierarchical work structures are transformed into flexible networked structures across several locations (Loebbecke & Picot, 2015). However, Papadakis et al. (1998) report that companies have a manager-centric authority in situations that are more threatening.
Knowledge sources	Value chain level: The sources through which companies learn about new management practices to guide their decision-making process strongly predicts the adoption of a DDDM process (Constantiou & Kallinikos, 2015; Brynjolfsson & McElheran, 2016). There are several sources from which companies are learning, such as consultants, competitors, suppliers, customers, trade associations or conferences, new employees and headquarters (Brynjolfsson & McElheran, 2016). Besides traditional outsourcing, companies are becoming increasingly flexible with integrating external freelancers or labour, for example by crowdsourcing ideas or processes (Loebbecke & Picot, 2015).

Analytical framework: linking the concepts

Altogether, the literature review has led to the development of the analytical framework (figure 1). In this research, the framework attempts to identify the key elements of the DDDM process of manufacturing companies. The aim of this research is to explore the suitability of the analytical framework developed upon the recent literature and to provide guidance for strategy and policy mechanisms. As such, the analytical framework serves as a guidance for the empirical research.

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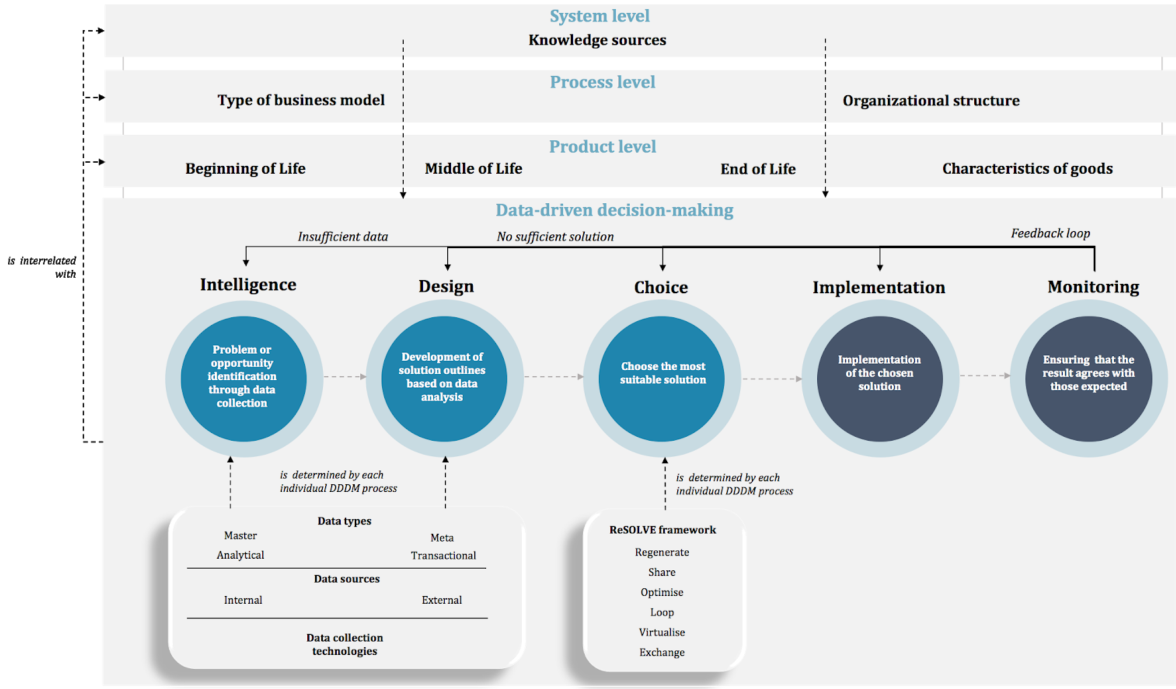

Figure 1. *Analytical framework*

3.Methods

The objective of this paper is to investigate how DDDM fosters CE strategies in manufacturing companies. In order to reach this objective, an exploratory multiple case study is conducted. A multiple-case study offers the opportunity to examine the operation of causal mechanisms of companies in contrasting or similar contexts (Bryman, 2016). The goal is not to generalize the findings to the manufacturing sector at large or to develop definite conclusions, but it is to get familiar with basic details and concerns of the phenomenon and to develop a well-grounded picture of the situation (Yin, 2009). This research studies the case of the manufacturing sector in the Netherlands. This case is particularly interesting as it is accelerating its transition towards a CE pushed by a governmental programme with the ambition to achieve full circularity by 2050 and a 50% reduction in the use of primary raw materials (minerals, fossil and metals) by 2030 (Rijksoverheid, 2016).

To this end, 11 manufacturing companies were selected based on the following criteria, all companies

(1) belong to one of eight largest industries in the technical or biological cycle; (2) are for-profit; (3) are operating in the Netherlands; (4) are experienced in the use of data in their decision-making process; (5) are facing challenges in the CE; (6) are middle to large in size (100 persons or more). Additionally, an expert company was included to clarify and discuss the empirical results through meaningful insights. The expertise of company Z is on the development of practical and scalable business solutions for the acceleration of the CE. Table 4 provides an overview of the companies studied, as well as their categorisation per specific industry. Having these companies from different industries allows for a more in-depth comparison of the DDDM processes for different products, manufacturing processes and industries.

***Table 4**. Participating companies and industries*

Company	Industry	Company	Industry
A	Medical equipment	G	Vegetable oils and fats
B	Complex equipment	H	Office furniture
C	Lightning solutions	I	Logistics and supply chain
D	Information technologies	J	Packaging
E	Construction panels	K	Cacao, coffee and vanilla
F	Steel plates	Z	Expert company

3.1Data collection

Data was obtained from secondary data sources and semi-structured interviews. In this research both qualitative and quantitative secondary data are used that were gathered through company websites and the internet. The secondary data is mainly based on digital or paper-based sustainability reports, annual business reports, product brochures and organisational websites such as from the Ellen MacArthur Foundation and Circle-Economy. The collected information was used before the interviews to increase the researcher's knowledge on the company and its supply chain and after the interviews for the individual case analysis.

In this research, 12 semi-structured interviews were conducted as the primary data gathering method, which involved the use of predetermined open-ended questions and topics (Berg, 2001). The specific questions and topics were constructed in an interview guide. The questions were focused on the DDDM process of companies over a period of 5 years (2014-2019). The topics covered by the questions are: company details, interviewee details, circular strategies, DDDM process, challenges and enablers, and future steps. The semi- structured questions were asked in a systematic and consistent order however the interviewees were allowed to probe beyond the answers to the questions.

The interview first started with an introduction of the research and the researcher. Next, the participant introduced the company and his or her role in the company. The second part of the interview consisted of open-ended questions, which were further categorized into topic related parts. During the third part of the interview open questions were asked and additional comments were made. In order to improve the efficiency of the data collection process and avoid data loss, each interview was digitally recorded. One person from each company with roles and functions related to sustainability, corporate social responsibility (CSR), circular economy, data analytics or data management was interviewed. All interviewees were contacted through email or in person. The semi-structured interviews were conducted in-person, over the phone or through Skype.

3.2 Data analysis

After the qualitative data from the semi-structured interviews was collected, the data was transcribed and analysed through a three-step coding process. During this process the data was condensed and made systematically comparable. The goal of the coding process was to discover and code concepts, find interrelationships between the codes and compare the codes of each company case. After the coding and analysis process, a within-case report was written for each case. This report was peer reviewed by the corresponding company to ensure the correctness of the findings. After the individual check, a cross case

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analysis was performed based on a pattern matching approach after all the conclusions were analysed of the individual cases.

4. Results and Discussion

The results derived from the semi-structured interviews and the secondary data analysis are subdivided in four sections. The first section reveals how the entire DDDM process across companies is shaped for circular strategy development. Section two explores the variations in each step of the DDDM process across companies and the challenges faced during DDDM. The third section unfolds which factors on product, process and value chain level are affecting the steps of the DDDM process across the cases. Finally, section four reflects on the analytical framework presented in figure 1.

4.1The entire DDDM process

The analysis reveals that the DDDM process is an iterative process, in which companies reflect on and adapt their decisions. The theories of Simon (1960) and Huber (1980) on the strategic decision-making process, imply that the process is a linear model that seems to be orderly and progressive. However, it occurred in several organisations that decision makers changed direction within the process. This result reveals that complex business decisions are often semi-structured or unstructured, as theorised by Gorry & Morton (1971).

Unlike previous empirical research, which has focused on DDDM and CE strategy development separately, this study explored the link between the DDDM processes and circular strategies. As a result, a taxonomy is developed to map the link between the two dimensions. The dimensions combined classify four types of relationships, which each result in different levels of performance outcomes (figure 2). The empirical results show that there is a fast-growing intersection between DDDM and circularity within manufacturing companies that is still in its infancy. The role of data is becoming increasingly important in strategy development to accelerate the CE.

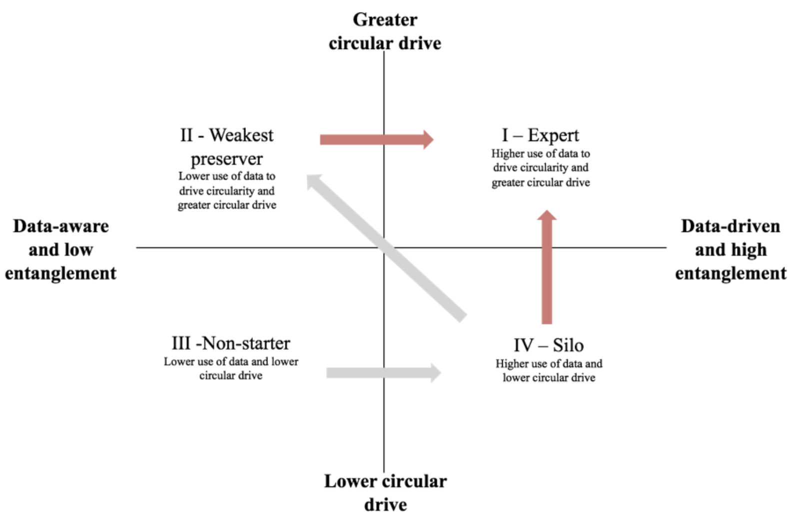

Figure 2. *Four types of relationships*

The 'Experts' in quadrant I represent the companies where data plays a central role in as many decisions as possible across and within departments, as well as where the circular drive is greater than in other companies. Manufacturing companies in this position are effectively differentiating themselves from competitors by using data and technologies for strategy development that drive circularity and for measuring progress with circularity indicators. The 'Expert' state can be achieved by sharing valuable data across departments and companies, and by creating a mutual understanding of the CE. In this research none of the companies can be placed in this position. The results reveal that companies either demonstrate a greater drive for circularity but lower levels of data use, or high levels of data use but not in circular decisions because of a lower circular drive.

The 'Weakest preservers' in quadrant II describe the companies that are aware of the importance of data collection and may use it for monitoring but are not always basing decisions on it. The companies do have a higher circular drive than others. In this position, companies have implemented on average more circular economy initiatives within the organisation, but the company is often resistant to open data sharing across departments and companies. Insufficient or incomplete data sharing within and across companies can reduce the effectiveness of the strategy. The internal capabilities, such as technologies and data science of these companies need to be improved in order to develop an effective decision-making process and achieve a better performance. According to expert company Z, the reason for this is that the use of data through innovation is a relative new phenomenon in the manufacturing sector. This study reveals that company A, C, E and H are within the position of the weakest preservers, because the implemented circular strategies were mostly not data-driven. Company A, C and H are transforming towards the expert quadrant by improving their internal capabilities on data and technology management.

The 'Non-starters' in quadrant III represent companies that are data awareness and have a lower circular drive. These companies show low levels of data and circularity integration within their organisations. Companies in this position need to create internal awareness on the possibilities and outcomes of a CE. Moreover, these companies need to improve capabilities on technologies and data science. Otherwise, their future position may not be secured. All the companies analysed in this study cannot be placed in this quadrant, because all cases demonstrate either a higher circular drive or a higher use of data in decision-making.

The 'Silo's' in quadrant IV describe companies that demonstrate a high level of DDDM across and within departments of the organisation, but a lower circular drive than other companies. This position is achieved when companies share and integrate data across departments, but do not consciously apply data to circular decision- making. This narrow view on data use within organisations is not sufficient enough to gain a competitive position. Companies in this position need to strategically use data to increase business circularity that can ensure the company's future. This research has unveiled that companies B, D, F, G, I, J and K are within the silo position, because data was mostly used for strategy development unrelated to the CE. Companies D, G, I, J and K are transitioning towards the expert position by integrating data into circular strategy development and by using data in circular metrics to measure progress.

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4.2 The steps of the DDDM process and challenges

This research has found evidence for significant variations within each step of the DDDM process across companies. Within the intelligence step, the results reveal four problems why companies are increasing circularity: lack of finite natural resources, pressure from governments and legislations, increase in demand and population growth, and climate change. Furthermore, three opportunities are recognised by the companies: the possibility to create value in different ways, the possibility to innovate and digitalise, and the possibility to turn waste into valuable resources. The expert company Z confirms that climate change is a major challenge for the manufacturing sector, especially on process level. However, company Z foresees opportunities to increase resource efficiency in the operations through innovation which will result in cost and energy savings.

In the design step, the use of data and technologies variated across companies. As argued by the information processing view of Galbraith (1974), the empirical evidence revealed that the more complex a decision is, the greater amount of information is needed to achieve a given performance level. Galbraith (1974) argued that there are two general strategies to cope with the increasing data. In this study, companies increased their capabilities to handle more data by making more use of technologies or external sources. Furthermore, the study reveals two trends in which software and hardware solutions are used to support, enable and improve the efficiency and effectiveness of the DDDM process. The first trend is that companies are using software data to replace hardware or equipment. For instance, company A (medical equipment) and D (IT) have replaced hardware products such as data centres with virtual solutions such as cloud computing. This reduces the amount of materials and resources needed in the companies. The second trend is that companies are using software data to enhance hardware, products, equipment or value chain activities. For example, data from life cycle assessment (LCA) software enhances the traceability and transparency of materials and products within the value chain.

In line with the latest literature on circular strategies (Lewandowski, 2016; Jabbour et al., 2017; Ellen MacArthur Foundation, 2015a), this research observed in the choice step that data and technologies support the six main strategies of the ReSOLVE framework. The implementation of two additional circular strategies were unveiled in some of the companies: increased collaboration and supply chain transparency. Increased collaboration with governments and between industries has accelerated the CE within several companies. However, company Z believes that manufacturing companies are not connected enough within and across industries and through the value chain. Furthermore, increasing transparency and traceability is primarily mentioned by commodity producing companies because those companies are aiming to improve circularity at their supply base.

Lastly, this study found empirical evidence that challenges in DDDM for circular strategy development are consistent across three themes: data and technology related, company related, and value chain related. Within the data and technology theme, data privacy is seen as the biggest challenge. Personal medical information, behavioural information from light sensors or information of forest areas should be handled and stored properly. Expert company Z confirms this challenge and foresees an important role for policy mechanisms to improve this. For instance, by aggregating groups of companies based on material flows and gather information in data clean rooms, which are shared environments, secured from external access, between companies where each company determines the degree of visibility to their data. These challenges suggest the need for instituting strong policy mechanisms around DDDM. The challenge within the company theme is related to the data sharing across decision-making processes within a company. Not sharing valuable data internally can result in missed opportunities to increase circularity. Conversely, sharing valuable data internally can violate data privacy regulation. Within the value chain theme, two challenges are consistent across companies: getting governmental support for circular initiatives and collaboration with suppliers or customers and between industries.

4.3 System factors affecting DDDM

This research adopts a similar position to Jawahir, Badurdeen & Rouch (2015), in viewing that the DDDM process needs to be embraced on product, process and value chain level. The results reveal that the closer the decision maker is to the system level, the higher the ability is to gather data and transform it to actionable knowledge, as theorized by Mandinach, Honey & Light (2006). System factors may facilitate or inhibit the DDDM process to accelerate the CE. On product level, the results suggest that DDDM is influenced by the product's life cycle stage in which the decision is made. For instance, if companies seek to solve a problem on the sourcing of raw materials, it is more likely the company is gathering and analysing data from the beginning of the life cycle. Furthermore, the results reveal that the characteristics of the asset influences DDDM. The characteristics established in this study are: type of asset (product or commodity), length of product's life span, mobility of the asset, level of customisability and the complexity of the product's design. For instance, company B is producing complex equipment that has an average lifespan of 10 years and is assembled and used in one location. The length of the lifespan and the immobility of the system enables the company to collect data for a consistent period of time (10 years) under the same environmental conditions (the customer's location). This example demonstrates how the product characteristics mobility and life span influences the data collection process.

On process level, two factors are consistently influencing the steps of the DDDM processes: type of business model used and the organisational structure. For the latter, the interviewees emphasised the importance of top down and bottom up commitment in strategy decision-making. Furthermore, in line with the literature (Loebbecke & Picot, 2015), the traditional hierarchical structures are transformed into flexible networked structures. It was also observed that a company's business model can influence the DDDM process. A service-oriented business model enables companies to keep ownership and control over the products during and after the use phase. The results suggest that the same companies are gathering more user related data during the middle of life stage and are implementing more end of life strategies, such as remanufacturing or refurbishing. Even though existing literature has found evidence that a larger firm size and a higher educational level of employees influences the comprehensiveness of DDDM, this study has not observed this connection. On the contrary, in some cases this study unveiled that smaller manufacturing companies without high educational levels in IT or data science, still have comprehensive DDDM processes. This can be explained by the external knowledge sources used by the companies.

Lastly, consistent with the literature on knowledge sources (Constantiou & Kallinikos, 2015; Brynjolfsson & McElheran, 2016), this research unveils that external knowledge sources are influencing DDDM on value chain level. Primarily companies that do not have in-house knowledge on data and technology use, partner with

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external start-ups, industry players or IT companies. Moreover, companies that rely on data collection from suppliers often collaborate with external consultancy companies or research institutions. For instance, company J has performed several LCA studies that are impartially peer reviewed by a third party. The third party also supports the company in gathering primary data from suppliers, while keeping data confidential.

4.4 Reflection on the analytical framework

In the current academic literature on decision-making, no framework was identified that integrates circular strategy decision-making with the use of data from a system perspective. Therefore, the preliminary analytical framework underpinning this study is developed from scratch and grounded firmly in literature on DDDM, CE and systems theory. Even though this initial framework is preliminary, it was essential for a thorough understanding of the interconnection between DDDM and CE. The aim of this study was not to conclusively verify the process in the framework. Rather, it was used as an overall base to explore and discuss the results. Future research ought to develop this framework further.

5.Conclusions

The previous sections have demonstrated the dynamic interconnections between the steps of the DDDM process, circular strategies and the system level factors. Building on this idea, it can be argued that DDDM needs to be viewed from an interconnected system perspective that is influenced by several value adding system factors. Manufacturing companies that fail to embrace these interconnections are risking the implementation of an incomplete strategy. By contrast, embracing this approach leads to a comprehensive and inclusive DDDM process. The results demonstrate significant variations within DDDM across companies, therefore strengthening the growing body of literature on the importance of data to accelerate the CE. However, de results also indicate several challenges related to data privacy, internal data sharing, and collaboration with governments and between sectors. Lastly, the in-depth interview results show that many system factors influence DDDM for CE strategy development.

Overall, the results show that government policy plays an important role in easing or restricting the transition to digitalisation and CE. First, policy needs to support creativity and provide guidance to manage the complex questions raised by data use and the CE. Second, the results unveiled that data privacy and security is increasingly becoming a challenge for companies. In order to address this challenge, governments can develop new policy mechanisms that enable shared and secured environments between companies where each company determines the degree of visibility to their data. Third, policy and tax incentives are needed to guide how assets are being designed and managed along value chains and across use cycles. Moreover, adjustments in the accounting rules are needed to enable the service business models. Lastly, governments play an important role in providing the sector with the bigger picture. Policies can guide companies to the areas where data and CE can make a difference, which again is dependent on data sharing across industries. By solving these challenges, governments can create the base for a circular and innovative economy.

Finally, some limitations of the adopted approach are identified and possible implications for the conclusions are discussed. The first limitation is regarding the generalisability of the results. The 11 manufacturing companies included in this exploratory study originated from different industries. In order for it to be representative for the entire manufacturing sector, more cases need to be investigated in several industries. Moreover, it would be interesting to know if there is a connection found between CE and DDDM in other countries. Lastly, future research is needed on the impact of DDDM on the company's performance. It will be interesting to research when a decision is 'good', and if good data insights will result in good or bad decisions.

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Applying the principles of CE in the context of concrete: A review

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Abstract

Construction and demolition wastes (C&DW) are considered a major waste issue within the European Union (EU), representing a third of all the waste generated in Europe, or approximately 800 million tons per year. One third of the C&DW consists of concrete waste. In line with EU ambitions to move towards a more sustainable economy, extending product life-time, reuse, recycling and other ways for material recovery are strongly encouraged. Experts from both academia and businesses suggest applying the notion of circular economy (CE) is a way to underline the large environmental and economic benefits that reuse and recycling of concrete could actually bring to the industry. However, reuse and recycling rates of concrete vary significantly within the EU, with an average rate of between 30%-60%. In Denmark, for example, almost all end-of-life concrete is considered waste and used either as road sub-base, or as other lower value applications.

There is still a large untapped potential for alternative applications of recovered concrete linking to the inner CE loops. Through a literature review and a two-year collaboration with a Danish cement producer, three strategies have been identified as having the largest potential for enabling CE in the context of concrete. The three strategies are recycling crushed concrete as aggregate for new concrete, reusing complete concrete elements in new buildings and extending lifetime of concrete structures. Some of the main barriers for enabling those strategies are also highlighted. This paper concludes with emphasizing the importance of collaboration between actors along the whole value chain of concrete for moving towards a more CE.

The outcomes of this study are expected to feed new insights on the relevance of rethinking current practices of handling products at their end-of-life, as well as suggest ways to design and implement CE principles in the context of construction materials and buildings.

Keywords: Circular Economy, Concrete, Construction Industry, Recycled Concrete Aggregates, Reuse, Product Life-Extension

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1.Introduction

Concrete is the most commonly used material in construction (Xiao, Wang, Ding, & Akbarnezhad, 2018), composed by cement, water and aggregates such as sand or stone. The mixture proportion of the three ingredients determines the physical and esthetic properties of the concrete (Miljøstyrelsen, 2018). The extraction of natural aggregates, their transportation and processing for the production of cement lead to large negative environmental impacts, accounting for much as 7 per cent of the global CO_2 emissions (Akhtar & Sarmah, 2018) and about 15 per cent of the global industry energy use (Sagastume Gutiérrez, Cabello Eras, Gaviria, Van Caneghem, & Vandecasteele, 2017). Due to the rapid boost in construction, those impacts are only expected to increase in the future (Stafford, Dias, Arroja, Labrincha, & Hotza, 2016). Additionally, even though structures are dimensioned to last for at least a couple of decades, many of those get demolished prior the end of their actual service life (Thomsen & Van der Flier, 2011). The demolition process creates large volumes of construction and demolition waste (C&DW), more than one third of which consists of concrete waste (Oikonomou, 2005).

The prior focus of the construction industry for improving the energy performance of buildings is now shifting towards capturing the embodied value and energy of building materials (Pomponi & Moncaster, 2017). Hence, an opportunity rises to adopt circular economy (CE) rationale in the context of concrete (Leising, Quist, & Bocken, 2018). CE is gaining an increasing focus by both industries, politicians and researchers since it addresses the rising issue of the current 'take-make-dispose' economy (Blomsma, 2018). In its core, the concept of CE is about avoiding waste through designing long-lasting products that can easily be disassembled to be serviced or repaired, as well as minimizing waste through reuse or recycling of materials and components (Ellen MacArthur Foundation, 2013).

According to Leising et al. (2018), although CE potentials can easily be highlighted, the processes and tools needed for realizing those potentials on a large scale are still in their infancy, especially in regard to the construction sector. On the one hand, there is an abundancy of cases, where recycled concrete aggregates (RCA) are used in new concrete, as a way to avoid the use virgin resources and lower material costs, some examples are (Rao, Jha and Misra, 2007; del Rio Merino et al., 2010; Lockrey et al., 2016; CSR.dk, 2018). Even though this practice is widely spread in some parts of the world, in Denmark today almost 90% of concrete at demolition is crushed used as RCA only for low value applications (e.g. road base filler) (Ministry of Environment in Denmark, 2015). This existing lack of common understanding of the opportunities and barriers of CE in the context of concrete calls for further analysis.

Through a literature review, this study aims at providing an overview of the CE potentials, as well as the currently existing barriers for transitioning of the concrete sector towards CE. Additional insights were gathered during a two-year collaboration with a Danish cement producer, which gave the opportunity to interact with representatives from the construction industry. As a result, this study emphasizes the importance of collaboration along the whole value chain of concrete, i.e. from suppliers of raw materials, to construction companies, end users, service and maintenance providers, demolition and recycling companies, for the transition of the concrete sector towards CE.

This paper is structured as follows: Section 2 includes a short description of the methodology applied in this study. Section 3 provides an overview of the existing opportunities and barriers, as well as existing practices in the concrete industry. Section 4 summarizes the main findings and opens up for a discussion on the importance of collaboration along the whole value chain of concrete.

2.Research methodology

The first step is conducting a systematic literature review of current publications in order to identify already established CE practices and existing barriers for implementing CE in the context of concrete. Publications available in English language on the search engine Scopus using keyword "circular economy" AND "concrete", "building sector", "construction" between the years 2006 and 2019 are determined. This research resulted in 461 publications present on Scopus. An extra search with keywords "circular economy" AND "concrete" AND "barriers" did not add any relevant publications on the topic.

After the Scopus search, an additional criterion is established. The publication must originate from the environmental science, materials science or management domain in order to be considered relevant for further analysis. The motivation behind adding this criterion is the scope of the study itself, which is primarily aimed at audience from the sphere of management, environmental science and businesses.

EU Waste Framework Directive 2008/98/EC, which places requirement for C&DW handling, as well as Directive 89/106/EEC setting requirement for construction products, are also included in the scope of analysis. The web is furthermore scanned for relevant reports on "circular economy" AND "the built environment", where 9 relevant technical peer-reviewed reports were identified and included in this study. An overview of the number of publications analysed can be found in Fig.1.

Thereafter, the collected data is followed by an in-depth analysis, discussed in the proceeding sections. Suggestions on how future studies can further analyse the topic adds an interesting extra layer to the discussions. In addition to the literature review process, a two-year close collaboration with Aalborg Portland, a Danish cement producer, gave the opportunity to enrich the understanding on the construction industry's view on CE. Aalborg Portland has experience with CE from a production perspective and is involved in diverse research projects on sustainable resource use. The close contact with the cement company opened up the possibility for interaction with a wider network with diverse actors along the whole value chain of the construction industry. That contributed to increasing the legitimacy of the literature review findings, since it confirmed the identified practices and existing barriers in literature through "real-life" cases.

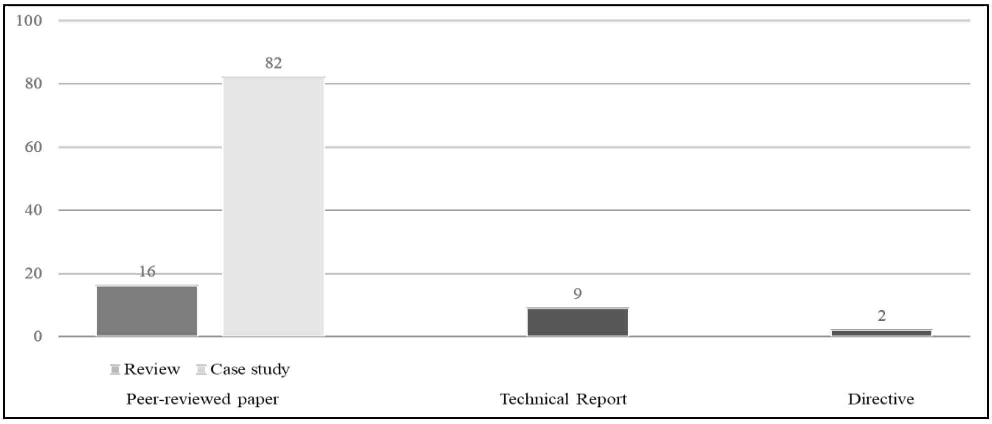

Figure 1. *Number of analysed publications per type.*

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3.Circular economy (ce) in the context of concrete

CE is opposes the conventional linear 'take-make-waste' economy, and introduces the notion of efficient resource recirculation (Loiseau et al., 2016). CE incorporates elements from diverse scientific fields (Korhonen, Nuur, Feldmann, & Birkie, 2018), one of which is industrial ecology (IE) (Bocken, de Pauw, Bakker, & van der Grinten, 2016). IE looks at industrial activities as a biological system where waste does not exist, but instead all residues are being utilized (Graedel & Allenby, 2003). In a similar fashion, CE is defined by the well-known Ellen MacArthur Foundation as an industrial system that ensures sustainable economic growth by circulating products and materials in the economic system at their highest possible value, for as long time as possible (Ellen MacArthur Foundation, 2012). One of the ground principles of CE is prioritizing 'reuse' over 'recycling' or 'maintain' over 'reuse', as the fewer modifications of the product or material, the greater the cost savings and the lower the environmental externalities (Ellen MacArthur Foundation, 2013).

3.1Current CE practices and existing opportunities

According to the identified relevant literature for this study, until recently the construction industry has mainly been giving focus on optimizing the energy use of buildings or simply reducing construction waste through recycling of C&DW (Karen L. Scrivener, Vanderley M. John, 2016; Leising et al., 2018; Lucon et al., 2014; Tebbatt et al., 2017). Recycling C&DW, and, in that regard, recycling concrete, is a widespread activity after demolition in many parts of the world, diverting waste from landfill (Deloitte, 2017). Nevertheless, recycling concrete usually results in 'downcycling' the material, since the derived recycled concrete aggregates are most commonly used for low-quality applications, such as road-base or pavement (Zhang & Mabee, 2016). Based on the CE principle of prioritizing first the CE strategies that require the least modification of a product's properties, such as 'maintenance' and 'reuse' over 'recycling', using recycled concrete aggregate for applications that reduce the value of the material are considered a least-preferred alternative. Based on the conducted literature review, three main CE strategies have been identified as having the potential to enable CE in the context of concrete. The three CE strategies are summarized in Fig. 2, and will be discussed in the proceeding paragraphs.

Recycling concrete as aggregate in new concrete

Using recycled concrete aggregates (RCA) in new concrete has been demonstrated though a number of construction projects with varying substitution rates of virgin aggregates from 10% to 30% or even 45%-50% (Akhtar & Sarmah, 2018; Wijayasundara, Mendis, & Crawford, 2017). According to a report from the Danish Environmental Protection Agency, if using recycled aggregates in new concrete is to be done in a sustainable way, transportation of aggregates needs to be minimized (Miljøstyrelsen, 2018). Sorting and crushing of the concrete can be done at the demolition site, followed by strict quality control through screening, after which the aggregates can be used for casting new concrete elements. Countries, such as The Netherlands, Germany, Switzerland, Japan, Belgium have for long time used RCA in new concrete as a way to deal with limited landfill space or limited access to aggregates (Miljøstyrelsen, 2015).

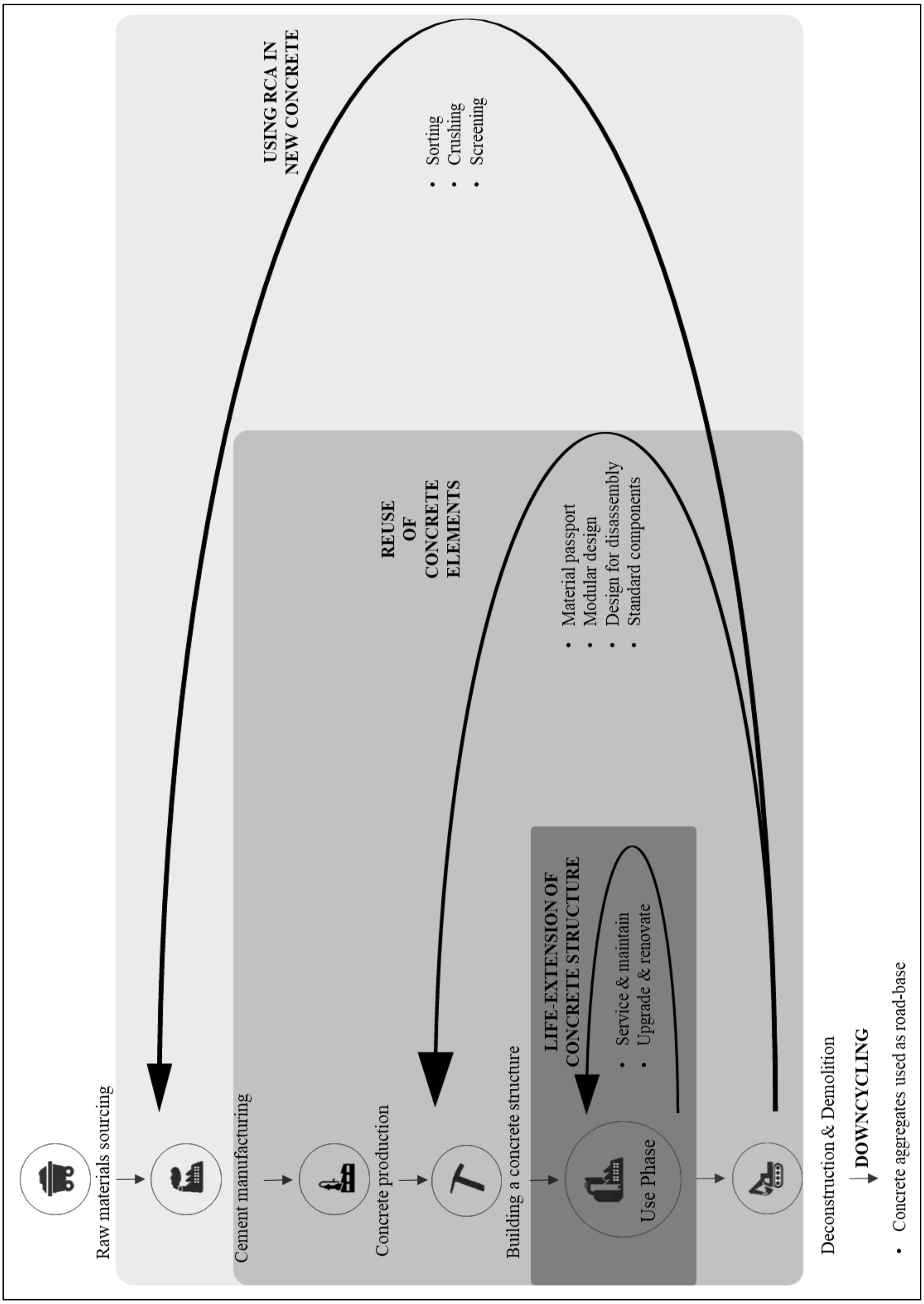

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Figure 2. *Circular business models identified based on the analysis of existing practices.*

Reuse of concrete elements

Reuse of concrete requires dismantling the concrete into elements, which can then be utilized in new construction. Today the reuse of building elements, such as windows, doors, even bricks, is a widespread activity. Nevertheless, when it comes to reusing concrete elements, the way buildings are designed and built today makes it a hard task, both due to their non-modular design, but also with regard to the composition of the used materials (Miljøstyrelsen, 2015). A study conducted by Honic, Kovacic, & Rechberger (2019) suggests material passports (MP) as a successful method for mapping the material composition of both existing and new buildings. MP is considered a supporting tool for CE in the construction sector, since it provides detailed information about the properties of the used materials.
A report from the Danish Environmental Protection Agency (Jensen & Sommer, 2018) highlights the importance of rethinking the design of buildings, in order renovations as well as retrieving useful elements to be easily done. A number of examples from The Netherlands show how standardized modular concrete elements can be demounted and reused directly in new buildings (Jensen & Sommer, 2018).

Life extension of concrete structures

Considered the most "inner" CE loop, extending the lifetime of concrete structures keeps the concrete material at its highest value and can be ensured through service, maintenance, upgrade and renovation (Ellen MacArthur Foundation, 2013). Numerous examples illustrating that in case a construction changes its purpose, i.e. an office building becomes a residential building or an old concrete dry dock is transformed into a museum, etc., it can be both economically and environmentally viable to avoid demolition (Yost et al., 2018). Instead, upgrading a concrete structure can extend its lifetime by placing new insulation or exchanging the windows, modifying the interior walls, etc.

3.2Currently existing barriers for enabling CE in the context of concrete

Even though the potentials of CE in the context of concrete are evident, a number of factors have been identified in the selected literature for this study, as potential barriers for enabling the three identified CE strategies. The barriers are summarized in Fig. 3.

Firstly, according to Gálvez-Martos, Styles, Schoenberger, & Zeschmar-Lahl (2018), a major financial barrier for the use of RCA is the currently low virgin material costs. In many European countries, extracted natural aggregates have a similar price to recycled aggregates. Secondly, GHG emissions related to transportation of aggregates as well as concrete elements is an important parameter when estimating the environmental impact of implementing CE principles in the context of concrete. Since concrete is a heavy material, studies show that emissions related to transportation from demolition site to either concrete factory or new construction site should not be disregarded and optimizing transportation distance of both concrete waste and retrieved aggregates should be of central concern in a CE setting (Mah, Fujiwara, & Ho, 2018). Thirdly, especially with regard to using RCA in new concrete Adams et al. (2016) points at the existing lack of confidence by the industry in the

quality of secondary materials. Nevertheless, numerous papers from academic literature also analyze diverse cases of reusing concrete aggregates and display both economic and environmental advantages, some examples are (Akhtar & Sarmah, 2018; Oikonomou, 2005; Tam, 2008; Wijayasundara et al., 2017; Xie, Gholampour, & Ozbakkaloglu, 2018). Yet, integrating those and other CE practices, such as design for easier disassembly, reuse of concrete elements or extending concrete life-time, requires highlighting the clear economic incentive for both construction companies and designers (Tebbatt et al., 2017). Lastly, legislation can be considered an obstacle with regard to limiting the amount of RCA in certain concrete classes and applications (Dansk Standard, 2008; Ministry of Environment in Denmark, 2015). Yet, recent construction projects, such as the newly built recycling station in Copenhagen replacing coarse aggregates with RCA without compromising the strength of the concrete (Dakofa, 2019), is one illustration of the possibility to work around the current legislative barriers and misconceptions by the industry. Legislation can also act as a barrier in connection to direct reuse of concrete elements. According to the EU legislation for example, a number of construction products require CE-marking (European Commission, 1988), which means that future reuse of concrete elements may require extensive testing and documentation of quality and thus, be a CE barrier. Additionally, a study by Charlotte, Eberhardt, Birgisdóttir, & Birkved (2018) underlines
the current lack of tools measuring the environmental benefits from reuse of construction materials and suggests life-cycle assessment (LCA) as a supporting method in decision-making.

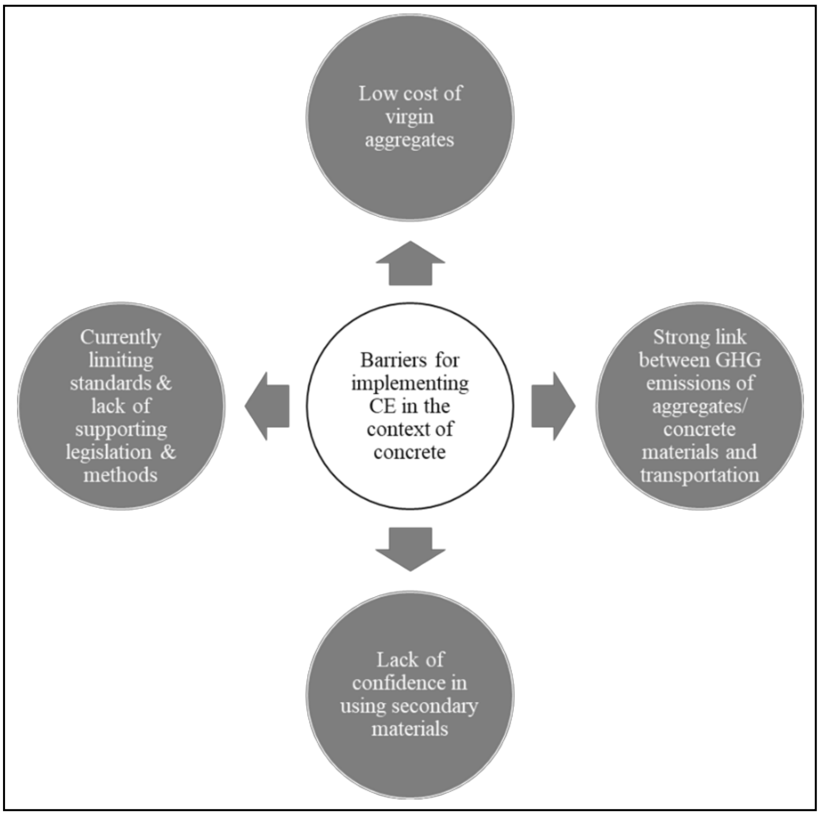

Figure 3. *Identified barriers for implementing CE in the context of concrete.*

4.Conclusions

This paper investigates the CE potentials in the context of concrete. Three CE strategies are identified and presented, i.e. using RCA in new concrete, reuse of concrete elements and life-extension of concrete structures. Furthermore, four barriers for implementing those strategies have been highlighted. In order to overcome those

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barriers and exploit the CE potentials, collaboration between actors along the value chain is crucial (Brown, Bocken, & Balkenende, 2019; Ghisellini, Cialani, & Ulgiati, 2016). Implementing CE solutions, such as reintroducing products and materials in the market or offering long-lasting products requires to "*consider sustainability in the entire supply chain and collaboration with supply chain partners is therefore required*" (Niesten, Jolink, Lopes de Sousa Jabbour, Chappin, & Lozano, 2017). Furthermore, Ness and Xing (2017) specifically underline the importance of collaboration between parties along the value chain of concrete i.e. suppliers of raw materials, construction companies, end users, service and maintenance providers, demolition and recycling companies, etc. Thus, a future study can assess in more details the potentials and challenges of implementing circular business models in the construction sector if collaboration between those actors is established.

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Evaluation of circular economy strategies through multilevel Statistical Entropy Analysis

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Abstract

Resources play a crucial role in delivering value to society. In the course of their appropriation, networks of processes produce substances of high purity, which are subsequently combined into components and products with very specific quality characteristics and functions. Thereby, previously concentrated substances are dissipated and diluted, requiring considerable efforts to regain their original functionality. Often, the process of re-appropriation of the original substance function is limited by physical laws, but also by socio-economic system structures. Some of these efforts could have been potentially avoided through a different system set-up, e.g. by a different combination of reuse and recycling strategies, contributing to a more circular and sustaining economy. One method that is able to assess the performance of systems to concentrate or avoid dilution of resources is Statistical Entropy Analysis (SEA). It has been developed to analyse the results of a Material Flow Analysis (MFA), which is a method that assesses flows and stocks of materials within a system. Until now, the method has been applied on the substance level (elements and compounds) only, but proved to be applicable to various scales and on a variety of systems. Some examples include the evaluation of the European and Chinese copper cycles, the process of lead smelting of a large state-owned enterprise, waste water treatment plants and municipal solid waste incinerators. By further developing the method we are able to combine all three hierarchical level, consisting of the materials, component and product level. This extension makes the method applicable to different combinations of CE strategies, both destructive (e.g. recycling) and non-destructive (e.g. reuse). The method is demonstrated on a case study of a simplified production and end-of-life treatment system of a car, under eight different system configurations. The results show that the multilevel SEA method allows to evaluate the contribution of different CE strategies and their combinations to maintain and restore functionality, while identifying critical stages which lead to the most severe resource and functionality losses. Based on the results, first a circularity baseline is defined which represents a system state which fully preserves functionality and avoids resource losses. In a second step, the dilution and concentration changes that are undertaken within the system to reach a specific system state are included, resulting in the framework for resource effectiveness. Based on a system's ability to preserve

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or regain the functionality of substances, components and products (x-axis), under the simultaneous consideration of statistical entropy changes that are undertaken (y-axis), the framework assesses the relative distance between system configurations, as well as their distance to the ideal state of resource effectiveness. The ideal state of resource effectiveness is represented by a system that maintains maximum functionality with minimal statistical entropy changes (efforts). Within the two dimensions of the framework any system configuration can be quantitatively assessed. As the method is independent of any background system, e.g. energy system, it is complementary to multiple methods, including impact- and cost-benefit evaluations, providing a high potential for their future integration. [word count: 493]

Keywords: Circular Economy, Statistical Entropy Analysis, Material flow Analysis, Recycling

1.Introduction

Human processes transform the biosphere to a degree, that has made human activity a force of geologic importance[1] (Vernadsky, 1926). One of the main reasons for that transformation is the core of the economic process, which is described by Georgescu-Roegen (1971) as an activity that transforms valuable "low entropy" materials into low value "high entropy" wastes and emissions. With the popularity of the circular economy (CE) concept, the principle of the economic process as an engine that also produces wastes and emissions is often neglected. Mismeasuring economic activity for quality deterioration, waste, emissions, but also the primary goal of the CE, the maintenance of functionality and value (European Commission, 2015), is unlikely to accelerate the CE transition.

In this context, one method that closely relates to Georgescu-Roegen's description of the economic process is Statistical Entropy Analysis (SEA). SEA is a method that evaluates processes and systems in terms of their power to concentrate or dilute substances, or to produce "low entropy" (e.g., a silicon wafer) or "high entropy" outputs (e.g., e-waste). The method has been developed by Rechberger and colleagues (Rechberger, 1999; Rechberger and Brunner, 2002; Helmut; Rechberger and Graedel, 2002; Sobantka et al., 2012; Laner et al., 2017) as an evaluation method that can be directly applied to the results of a material flow analysis (MFA).

Previously, the method has been applied to single substances (e.g., Rechberger and Graedel, 2002a) and compounds (e.g., Sobańtka et al., 2014). With the extension of the method to the material, component and product level (Parchomenko et al., 2019 submitted), the method can evaluate CE strategies, that target the level of the product (e.g., reuse), component (e.g., remanufacturing), and mateirals (e.g., recycling), including their combinations. In this conference paper, the method is demonstrated on different combinations of CE strategies, for the first time also including the process of remanufacturing.

2.Method

Statistical Entropy is a method that measures the distribution of a set of characteristics. Initially applied in information theory (Shannon, 1948), it was further developed to evaluate the results of a material flow analysis (MFA) (Rechberger, 1999; Rechberger and Brunner, 2002). When applied to the results of a MFA, it quantifies the power of a system to concentrate or dilute substances (Brunner and Rechberger, 2016). The rationale behind the method is that diluting processes lead to an increase in statistical entropy (H), while processes that concentrate substances, e.g., mining, refining, but also sorting and recycling, reduce H. The lowest H-value is reached if a substance is fully concentrated in one material flow. In that case, the H-value of the flow is zero. On the contrary, the more substances are mixed, or are diluted to the environment (outside the system boundaries), the more the H-value approaches the value one. Relating statistical entropy values to the highest possible level of dilution in the system allows to express statistical entropy as Relative Statistical Entropy (RSE), or Hrel, which is always located in the interval [0, 1].

[1] V. I. Verdansky uses the word 'noosphere' (Greek 'nous' for 'mind' or 'intellect') which refers to a world that is shaped by human thought, which includes scientific and technological development including related material transformations

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The method showed its applicability to a wide range of systems. It was used to analyze the European copper cycle (Rechberger and Graedel, 2002b), municipal solid waste incinerator technologies (Rechberger and Brunner, 2002), waste water treatment plants (Sobańtka and Rechberger, 2013), the Austrian phosphorus cycle (Laner et al., 2017), and the process of lead smelting (Bai et al., 2015). The method was further developed to assess chemical compounds (Sobantka et al., 2012), and to consider imports, exports and recycling loops (Laner et al., 2017). SEA was also adapted to measure the recyclability of electronic waste (Zeng and Li, 2016), and to assess mixtures of substances in a sieving experiment (Velázquez Martinez et al., 2019).

The most recent development of the method is demonstrated in the following. It integrates additional hierarchical levels, which includes the material, component, and product levels. Thereby, the lower hierarchical levels represent the building blocks for the next higher level, e.g., the distribution and variety of substances (and materials) in a component determines the H-value of the component, while the number, diversity, and the composition of components influence the H-value of the product. The rationale is similar to the material level. Products that consist of a larger number of different components, with a complex material composition, (e.g., smartphone), have higher entropy values than products that consist of fewer components with a simple composition (e.g., historic rotary dial phone). For a formal introduction of the method, please see (Parchomenko et al., 2019, submitted). This ability to express component and product entropy values allows SEA to assess, in addition to material based CE strategies (e.g., recycling), also CE strategies that target higher hierarchical levels such as remanufacturing and reuse, and combinations thereof.

3.Case study

For the demonstration of the method, a case study of a simplified car production and end-of- life treatment system is employed (Figure 1). The composition of the car is described by four component groups and six materials (Table 1).

Table 1: Simplified car model described by four components groups and six materials (Modaresi et al., 2014).

Group name	**Standard steel (kg)**	**HSS (kg)**	**Cast Iron (kg)**	**Wrought Al (kg)**	**Cast Al (kg)**	**Others (kg)**	**Total (kg)**
Body and closures	222	182	0	8	0.3	45	457.3
Chassis and suspension	203	41	17	10	23	37	331
Powertrain	99	0	94	4	41	108	346
Interior	61	0	0	12	2	173	248
Total (kg)	585	223	111	34	66.3	363	1382.3

The car model is employed in a simplified production and end-of-life treatment system (Figure 1). It describes the production of vehicles from virgin or recycled materials, as well as from reused or remanufactured components. In the first cycle, the system starts with the production of the vehicle from pure material inputs. After the production phase, the degree of reuse and remanufacturing determines the number of components that enter the shredder process. Components that are reused or remanufactured enter as inputs into the next production cycle. The output of the shredder can take two routes, (1) it can be recycled or (2) directed to the rest fraction that represents a mixed flow which leaves the system.

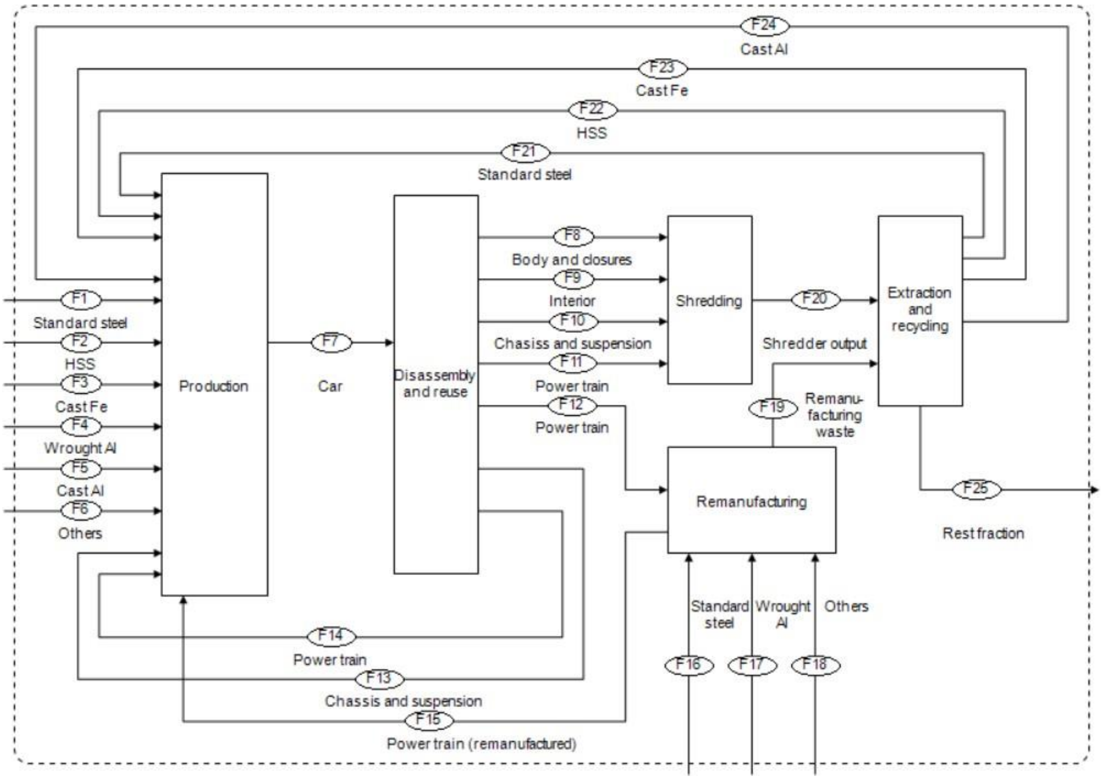

Figure 1: Illustration of the material flow structure of the simplified, production, reuse, remanufacturing, and recycling system.

Seven scenarios are employed to model different reuse, remanufacturing, and recycling rates and to assess their influence on the evolution of Hrel in the system (Table 2). The scenarios consist of a linear scenario (S1), a full reuse scenario with the reuse of all components (S2), two recycling scenarios (S3 and S4), as well as the remanufacturing (S5) and the reuse scenario (S6), where one component group is reused. Further, an additional linear scenario (S7) is employed, where remanufacturing is employed, but which fails to remanufacture the component, so that additional materials together with the component from the remanufacturing process are directed to the rest fraction (waste). The level of reuse, remanufacturing and recycling is described for each scenario (see Table 2). The different scenarios should demonstrate the rationale behind the method and show how the method could be employed for the analysis of other, more complex systems.

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Table 2: Seven scenarios with different rates of reuse, remanufacturing and recycling (Reuse and remanufacturing indicate the number of components reused or remanufactured, while the the remanufactured/reused component group always represents the power train).*

Scenarios	*Reuse**	*Remanufacturing**	*Recycling*
S1 - Linear System			
S2 - Full reuse system	*4*		
S3 - Recycling system 50%			*50%*
S4 - Recycling system 85%			*85%*
S5 - Remanufacturing system		*1*	*50%*
S6 - Reuse system	*1*		*85%*
S7 – Linear System with remanufacturing		*1*	

4.Results and discussion

The results of the analysis show the evolution of relative statistical entropy (RSE = H_{rel}) for each scenario (Figure 2). The evolution of H_{rel} starts with the lowest value (H_{rel} = 0) and identical H_{rel} values for all scenarios. It shows that initially, pure inputs into the system are identical. With the same first three production processes, the scenarios show the same H_{rel} values, while the increase in H_{rel} shows the dilution of pure material inputs into the product.

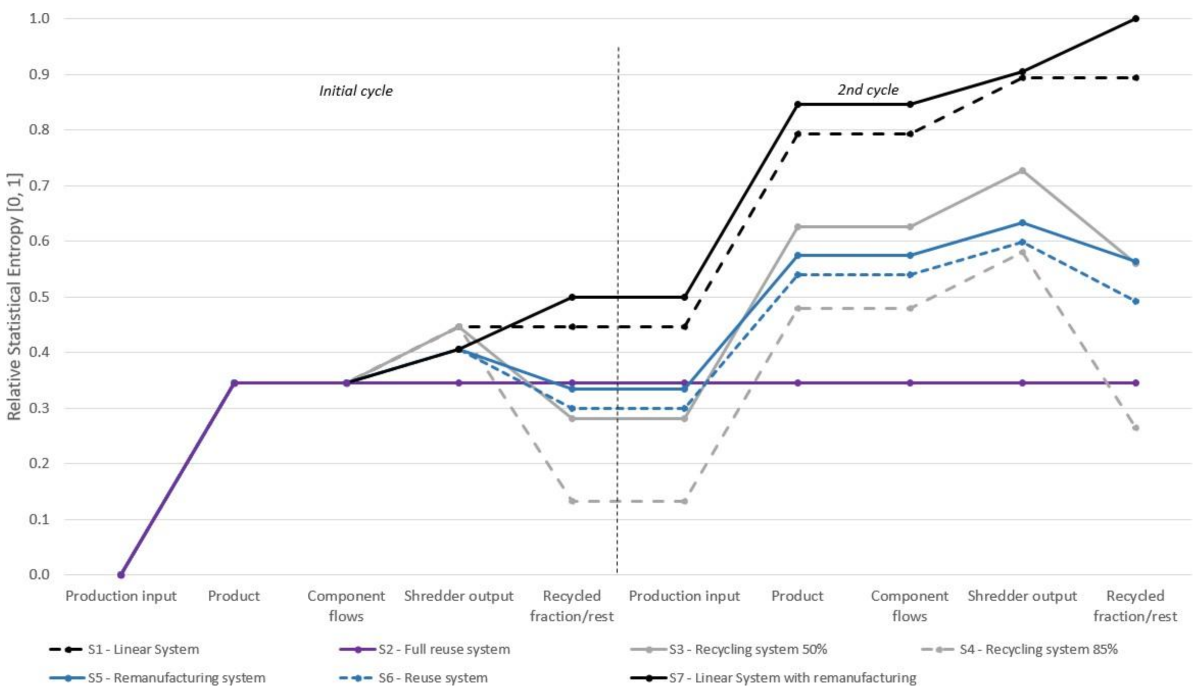

Figure 2: Evolution of Relative Statistical Entropy (RSE) for seven different scenarios over two system cycles.

After the production and the use phase, the vehicle reaches its end-of-life and its components enter the shredder process. Depending on the scenario, a different number of components is directed to the shredder, with maximally one component group being diverted to be reused or remanufactured. These differences in the diversion from the shredder process are responsible for the first deviations of the Hrel-curves.

In the linear system (S1) and the recycling systems (S3, S4), all components enter the shredder, where materials are mixed, which leads to the higher Hrel values for these scenarios. The recycling process lowers Hrel with the highest decrease for the system with a recycling rate of 85%. If no recycling is employed (S1 and S7), all materials remain diluted and are directed to the rest fraction, thereby leaving the system as waste. In that case, Hrel does not decrease, and all materials must be imported in the next system cycle.

While recycling can decrease Hrel values after these have been elevated, another strategy can be the avoidance of Hrel increase. This strategy represents the reuse or remanufacturing of a component (S5, S6). Reuse and remanufacturing decrease dilution at the shredder output by diverting a component from the shredder. When comparing the reuse and remanufacturing of a component, it shows that remanufacturing leads to higher dilution at the stage of the recycled fraction/rest. The reason is that remanufacturing requires additional material inputs which are used to restore the functionality of a component. Therefore, the remanufacturing scenario produces a larger waste fraction than the reuse scenario, which explains the parallel progression of the curves, with slightly elevated Hrel values for the remanufacturing scenario.
Another parallel trajectory is found for the linear scenarios with (S7) and without (S1) remanufacturing. In the first case (S1), $Hrel$-values never decrease, as no process such as recycling or remanufacturing is employed. Each time the functionality is lost on the component level (a result of shredding), as well as on the material level (a result of the dilution of materials to the rest fraction). Therefore, new material inputs are required to replace the lost functionality at each cycle. With the absence of reuse, remanufacturing and recycling, the linear scenario S1 represents a case that is far from being circular. Despite that, a worse case exists. The scenario S7 represents a system that employs remanufacturing, but which fails to restore component functionality and leads to additional material dilution from the remanufacturing process. The case shows the highest $Hrel$-values, indicating the largest material dilution and functionality loss.

In contrast to the linear scenarios, the highest maintenance of functionality is shown for the scenario with the reuse of all components (S2). Based on the previously introduced definition of the CE, the system which maintains functionality on the component (or product) level, represents the ideal circular case, as it allows to reuse all components and does not need any additional inputs, as well as any recycling or remanufacturing processes to enable the next system cycle. Therefore, it can be concluded: the closer a scenario is located to the ideal CE case, the higher is its effectiveness to maintain functionality and preserve resources.

Statistical entropy changes

Besides the evolution of $Hrel$, it is also important to consider the required changes in statistical entropy of each scenario ($\Delta Hrel$). Statistical entropy changes ($\Delta Hrel$) can be considered as the efforts that are undertaken in terms of concentration and dilution activities. In Figure 2, they are expressed as the vertical distance between

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data points of a scenario. Higher $\Delta Hrel$-values are present for scenarios with higher recycling rates, showing higher dilution and concentration efforts of the systems. The smaller the dilution and concentration activity in the system, the lower are the $\Delta Hrel$-values. Combining the information on $Hrel$-values of Figure 2 (distance to circularity) and the required $\Delta Hrel$ between system processes, a framework for resource effectiveness is derived (Figure 3). It holds two important features: (1) the maintenance of functionality (distance to circularity, *x-axis*), (2) under minimal efforts (expressed as cumulated $\Delta Hrel$-values, *y-axis*) (for more details, see Parchomenko et al., (2019), *submitted*).

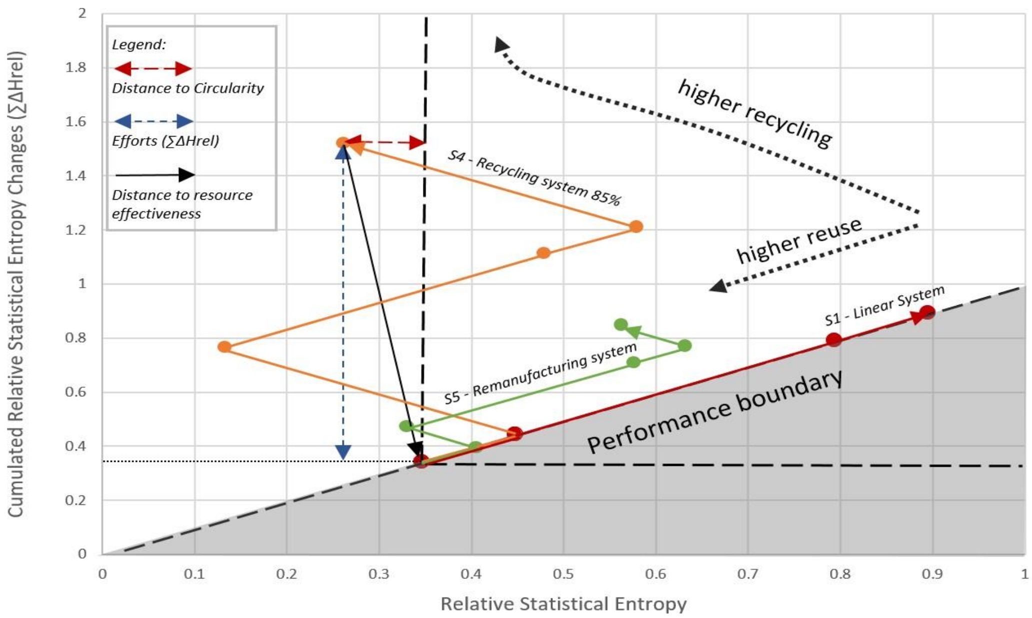

Figure 3: Resource effectiveness framework, exemplary showing relative statistical entropy (x- axis) and cumulated changes of relative statistical entropy (y-axis) for scenarios S1, S4, and S5, over two system cycles. For scenario S4, the distance to circularity of the final value and the efforts, expressed as $\sum \Delta Hrel$-values are shown explicitly.

The resource effectiveness framework directly relates the achieved $Hrel$-values with the required $\Delta Hrel$-values of a system. As the first processes of the system are identical, the system paths are plotted, starting from the point of the functional product. The linear system (red) follows a trajectory that never restores functionality, showing a path which translates each increase in $Hrel$ to $\sum \Delta Hrel$. In contrast, the recycling system (orange) shows an alternating path, with increases in $Hrel$, followed by large decreases in $Hrel$ that are achieved through recycling, resulting in overall high $\sum \Delta Hrel$. The path is longer, but the curve is alternating around the value of the functional product. The shortest path length of the three examples has the remanufacturing system (green). It avoids large increases in $Hrel$ through partially reusing a component and therefore requires lower $\sum \Delta Hrel$. From the resulting path length, it can be seen that the scenario is much closer to the point of the originally functional product (starting point of each curve). From the curves, it is shown how reuse, remanufacturing, and recycling affect the path progression of each scenario.

With the application of SEA, it can be shown that resources that are used to produce stocks that provide a

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functionality should be valued positively. The reason is that the use of these resources as functional product stock was the original purpose of their production, even though they prevent circular flows. In this context, indicators as recycled content could be misleading
as the recycled content could be low due to insufficient inputs into the recycling process (Rombach et al., 2012), effective stock management and durability of products, which avoids recycling, by maintainance of functionality on a higher level.

Therefore, the resource effectiveness framework demonstrates that reaching low entropy values does not necessarily represent a goal in itself. Typically it is a goal of a recycling process, while processes such as reuse, repair, and remanufacturing, aim to avoid entropy changes (ΔH) and maintain functionality on the component and the product level. In this context, the resource effectiveness framework indicates the absolute distance of a system (or a selected system state) to the originally functional product, thereby providing an alternative and combined evaluation approach for combinations of CE strategies on the material, component, and product-levels.

5.Conclusion

The evolution of statistical entropy over two system cycles demonstrates that the SEA allows to model multiple system cycles, identify hot-spots of functionality loss, (e.g., when components enter the shredder process), but also evaluate the maintenance of functionality (reuse of a component), and the restoration of functionality, both on the component level (remanufacturing) and the material level (recycling). By providing an integrated assessment of different CE strategies, the method shows that it can identify combinations of CE strategies, that minimize functionality losses and can thereby directly serve for the assessment of system circularity.

The reprojection of the SEA result in the resource effectiveness framework allows mapping the path of a system, in relation to the achieved functionality level and the required efforts. The path length directly shows the required changes of statistical entropy (efforts), while the location of a system state shows the level of functionality achieved. Thereby, the distance of any system location to the initial functional product state provides a measure for resource effectiveness.

The demonstrated case study provides an example of how the method could be employed also in more complex systems, providing a robust system evaluation, that is independent of any energy-, cost-, or impact-considerations, thereby providing a complementary evaluation tool to current CE assessments.

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Transitioning towards business models for circularity in the construction material industry-simulating the impact of policy interventions on regional material flows

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Abstract

Transitioning industry sectors towards more sustainable modes of production and consumption is the ambition of an increasing number of public policies. Recent reports indicate the speed of transition is insufficient to achieve sustainable outcomes within required time frames. This paper simulates regional material flows to understand the role of business models as systemic reasons for inertia to change, focused on the construction material industry.

Traditional business models couple economic success to material turnover, but increasingly face conflicts with the societal goal of resource efficiency. Traditional construction material business models provide products, such as gravel, cement and concrete, defining their role as material or resource suppliers. Business models present the dominant logic of production and consumption systems, hence are an important stepping stone to understanding drivers and barriers to sustainability transition. Understanding of business models and their role within an industry helps designing more effective mixes of policy instruments. The research project "Co-Evolution of Business Strategies in material and construction industries and public policies" uses idealized business models along the value chain for construction materials in Switzerland to understand the transition towards a more circular economy. Based on case studies with ten different companies, business models and the associated strategies are identified, reacting to developments in the socio-technical environment. Driven by regulations, standards and norms, companies extend their business models with additional services in waste management and logistics. On a company level, the analysis reveals how business-models differ in their respective resource consumption. To analyse the role of the different business-models on regional scale, a Material-Flow-Analysis (MFA) is complemented with System Dynamics (SD) simulation. The combination of material flows and associated decision-making rules results in a quantitative model. Derived from an idealized value chain of construction materials in a specific region, two business models are compared. The quantitative simulation helps understanding long-term developments as well as the impact of policy interventions. Resulting dynamics show path dependent behaviour and point at leverage points for improving resource management. A comparison between the results of a business as usual and a policy intervention, reveals how alternative business-models affect resource management and economic development on a regional scale. Preliminary results indicate that whereas public procurement policies stimulate circular products, local land allocation polices undermine these efforts. This results in a dominance of traditional business models over circular alternatives.

The research results enhance knowledge about the dynamics underpinning dominant regional business-models and sharpens the scope for policy interventions. It will provide decision support for public policies to accelerate transitions towards a sustainable build environment.

Keywords: Transitions, Barriers, Business Models, Simulation.

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1. Introduction

Traditional business models (BM) in the construction industry link economic success to material turnover. This promotes an inefficient use of natural resources and contradicts macroeconomic objectives, such as circular material flows and reduced material consumption (Halme et al. 2007). Increasing competition among construction material companies and pressure from public policies create a complex and challenging environment to existing and emerging business models. Business model adjustments have been observed along the entire value chain, challenging a cumbersome industry. Building contractors evolved towards service agents in material management of construction sites, resulting in turnover and profits becoming more independent of the consumption of natural raw materials. Increasing the focus on services rather than products attempts to decouple economic growth from resource consumption. This transition to a circular economy can be observed on entrepreneurial level in urban and rural regions, influencing regional material flows in Switzerland. Emerging business responses of companies focus on the preparation and use of secondary building materials. A dominant driver of this transition is the geographical and social limitation of access to natural resources, leading to fierce land competition among companies.

Diverse companies varying in size and degree of vertical integration can be found in the Swiss building material industry, but it is difficult to clearly differentiate between business models. Few large players with vertical integration dominate the market for concrete, ranging from the production of cement as well as concrete and aggregates. In recent years, innovative niche players started to dominate specific serves and products in urban areas. The share of construction companies providing material management as service on large construction sites including construction waste management, on-site recycling as well as concrete production has been increasing. To understand if public policies as drivers of these diversification dynamics can be an important lever in the governance of regional transitions, the following research questions is posed:

How can the success of alternative business models be explained by boundary conditions in local markets and incentivised by public policies?

In the research project "Co-Evolution of Business Strategies in material and construction industries and public policies" we try to answer these questions by identifying the most relevant business-models of gravel, cement and concrete producers in Switzerland based on case studies of ten different companies. We analyse how these business-models differ with regards to resource consumption and CO2-emissions. In a second phase of the research project we analyse how business model innovations can be encouraged by public policies to stimulate a transition towards a circular economy.

In this paper we present first results of the research, focusing on two gravel producing business models. The relevance of business-models on a regional scale is assessed within a case study region and complemented with scenario analysis for potential policy interventions.

2. State of research

2.1. Business-Models and transition management

This research builds on co-evolutionary transition dynamics, which can be described as the developments within subsystems, influencing the development of surrounding systems. For example, co-evolution between science and technology, between culture and technology and between technology and society (Geels 2002), between institutions and technology (Unruh 2000), or between organisations and institutions (North 1990) haven been researched. A number of studies presented empirical evidence for interdependencies between different societal subsystems, e.g. environmental regulation and the firms' competitive performance ((Ramanathan et al. 2017),(Testa, Iraldo, and Frey 2011)), environmental taxation and resource management (Söderholm 2011) or alternative business models (e.g. niche players) and mass market players (Schaltegger, Lüdeke-Freund, and Hansen 2016). For the case of construction materials, (Knoeri, Binder, and Althaus 2011) and (Knoeri et al. 2014) showed the
importance of planners and engineers as mediators between builders and construction industries for a transition towards resource efficiency. We understand business models as part of an industry regime, where reinforcing patterns of production and consumption form a dominant industry logic. Regimes play a central role in understanding transitions of socio-technical system, but conceptualizing the properties of regimes and their associated dynamics is subject to ongoing research (Köhler et al. 2019). Business models as part of a socio-technical system can be a relevant unit of analysis, if the goal is to understand the behaviour of the system (Bidmon and Knab 2018). The importance of competing business-models in a changing regulatory environment, however, has not yet been analysed for construction material industries and we try to fill this gap in our research.
In our analysis, we consider a business model as the articulation of a company's strategy (Richardson 2008). Literature suggests that value proposition (product/service, customer segments and relationships); value creation & delivery system (key activities, resources, technologies, etc.); and value capture (cost structure and revenue streams) form key components of business models (Osterwalder 2010). Research on sustainable business models expands this traditional framework by including social and ecological value creation for an extended range of stakeholders(Schaltegger, Lüdeke-Freund, and Hansen 2016).

Assessment of resource consumption

For the assessment of transition management in the built environment, defined as business environments for construction industries, material flow models are frequently used (an overview is given in (Augiseau and Barles 2017)). These studies mainly focus on stock-flow-models of defined regions (e.g. Switzerland) (Bergsdal et al. 2007; Dahlbo et al. 2015; Hu, van der Voet, and Huppes 2010; Rubli 2018; Wang et al. 2016), but also comparisons between nations or regions (e.g. EU 25) are available ((Haas et al. 2015; Wiedenhofer et al. 2015)).These models describe the underlying cause-effect only with coefficients related to the technical efficiency of processes involved (e.g. recovery rates). The main drivers of development are exogenous parameters such as rates of construction, demolition, or assumed correlations with socioeconomic parameters such as population number or GDP (e.g. (Bergsdal et al. 2007)). To overcome the limitations of a static model, driven by exogenous parameters, a quantitative System Dynamics (SD) model is developed. The SD model explains the behaviour of dynamic systems from an endogenous perspective. By identifying feedbacks between system variables, time delays and decision-making policies, SD assimilates several features that appear relevant to business model research. To understand endogenous dynamics, and the influence of policy interventions is

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at the core of System Dynamics, hence the chosen methodology appears promising.

3. Methods and Data

In our study, we identify and describe alternative business models combining methods from business administration as well as environmental and process engineering. In addition, we analyse a regional resource management system for construction minerals. In this section we present the methods used to collect relevant data.

3.1. Definition of criteria for classification and indicators

The analysis of business models is based on the definition of business models presented in (Osterwalder 2010) and complemented with aspects of research on sustainable business models (Schaltegger, Lüdeke- Freund, and Hansen 2016). For each business model the following aspects are analysed:

Value proposition: It describes how the organization attempts to create the willingness-to-pay of its target group to pay for the offered product or services (Osterwalder 2010). Furthermore, it describes the intended target audience, enabling evaluation whether the proposed value, relative to the company's competitors, is creating competitive advantage.

Value creation: Describing the operationalization of the company's strategy and internal value chain clarifies how the companies uses their resources and capabilities to create value for its stakeholders. Building on aspects from research on sustainable business models, the relevant stakeholders of an organization from a social and ecological perspective are considered (Upward and Jones 2016).

Value capture: Value capture completes the picture by examining how the company captures economic value from the consumer and the modes of transaction. (Richardson 2008) highlights that economic value is especially dominant in traditional entrepreneurial literature, distinguishing between the economic and revenue model. The captured value from incorporating sustainability describes the "business case for sustainability", combining profits with positive impacts.

We analyse how each business model affects regional resource management systems, economies and the natural environment. To this aim, we define several indicators (see Table 1). To compare different business models, we use each company's output of aggregates (in tons) per year as functional unit.

Table 1: indicators for the assessment

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Indicator	Unit	Description
Extraction		Most companies extract virgin gravel/sand from surface water or mine in gravel quarries. The rate of substituting virgin material with secondary resources can vary from company to company.
Recycling	ton per year	Excavated material is mostly used to refill empty gravel pits. In certain areas in Switzerland, however, the gravel content in excavated material is high enough to use this material as substitute for virgin gravel. In this case, natural resources can be preserved.
Import		Regional gravel deficits require the import of gravel from neighbouring regions. A high import quota conflicts with circular economy goals and indicates a resource dependency.

3.2. Collection of data

A case study with ten companies is used to determine the relevant BM. Each BM covers a specific step in the value chain of construction minerals, ranging from extraction of primary materials, over processing virgin/recycling aggregates, producing concrete, producing cement, constructing building and infrastructures and providing services in logistics, demolition, to sorting of construction wastes and waste management. Most companies' activities in this study focus on aggregate production with a variation in the degree of vertical integration as well as major resource input (primary versus secondary).

Table 2: collection of data

Workshop no.	Aim of the workshop	Data collected	Methods	Reference
1	Understand fundamental business model logic	Socially and environmentally extended business models perspective	Flourishing business models canvas	(Upward and Jones 2016)
2	Identify physical flows economic indicators associated with key resources, value proposition and value capture.	Material flows and respective prices and costs	Material flow analysis	(Brunner and Rechberger 2016; Kytzia, Faist, and

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				Baccini 2004)
3	Understand decision making criteria based on business model	Relevant economic and material flow indicators	System Dynamics simulation	(Groesser and Jovy 2016 ; Sterman 2000)

With each company, three workshops are carried out (see Table 2). In the first workshop, the companies' business model is analysed using the business canvas introduced in (Upward and Jones 2016). Thereby, the data collection exceeds purely economic aspects and includes social and environmental dimensions. In the second workshop, material flows, and production costs are analysed using MFA on company level. In the third workshop, the fundamental drivers of decision making, based on the insights of the previous workshops, are identified. The results of each workshop are discussed with the companies' representatives and validated with company internal data on material flows and costs.

[13] showed that consumption of construction minerals varies significantly from canton to canton due to imports and exports across the Swiss border as well as between cantons. To eliminate such effects, we chose an alpine region which is self-supplied with gravel and sand as well as landfill capacity. It is densely populated with around 82'000 inhabitants and its settlement growth rate is near the Swiss average. In this region, we can identify companies with different business models. In order to ensure confidentiality of all company data, we decided not to give any additional information on the region itself but to use it as a representative "model region" named ALPVAL (for "alpine valley").
The material flows in this region were assessed by interviews with representatives of all mayor companies located in the area. In addition, data was gathered from reports of the cantonal waste management authorities as well as statistics of gravel extraction from ground as well as rivers. Data on communal data was collected to additionally assess fees on gravel extraction.

3.3. Assessment of business models

The representation of each company builds on a Material-Flow-Analysis (MFA) and is complemented with data on associated decision-making rules, collected in workshops as described in section 3.2. The resulting model is simulated using a System Dynamics approach. A dynamic simulation of the competition between both BM's helps to understand the dynamics in favour of a dominant regime and the role of public policies in accelerating transitions.

4. Results

By conducting workshops with companies along the value chain of mineral construction materials, distinguishable features of multiple BM emerged. Eliciting features that are present in BM for the extraction and recycling of gravel, the unique attributes are summarized in Table 3. To differentiate between these two idealized companies, the value proposition, value creation and value capture are further discussed. As mentioned earlier, competition for land has increased the value of accessible land for extraction and disposal purposes. The relevance of these boundary condition will further be highlighted in the remainder of the discussion.

Table 3: insights and differences between the two business models

	Similar features	Distinction company A "Extraction"	Distinction company B "Recycling"
Value proposition	• Provision of gravel & concrete according to norms to construction companies. • Intake of disposable and excavation material • Local resource manager	• Desired equilibrium between intake of disposable material and output of gravel	• Material management on construction site as service. • Vertical integration Construction services • Development of Niche products for (1) specific application and (2) reduced primary raw material input
Value creation	• Disposal volume is profitable and scarce • Machinery and infrastructure	• Gravel extraction creates volume for disposal of material. • Focus on community management for organizational legitimacy	• Gravel extraction does not create volume for disposal. • Increase available volume for intake of disposal material with treatment of excavation material • Cooperation's with engineers aim at adjusting norms in favour of recycled products
Value capture	• Sales of loose gravel/ concrete (CHF/m3) • Accept disposal and excavation material (CHF/m3)	• Community management is crucial for access to key resources (land/gravel quarries)	• High quality products to increase uptake of recycling products.

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4.1 Identification of idealized business models

To showcase preliminary results from this ongoing research project, two representative BM are identified and discussed: BM "extraction" and BM "recycling". Both BM provide raw materials for the built environment and handle the material flows that leave the building stock. BM "Extraction" owns several gravel pits and sells waste management services for depositing excavated materials (in empty gravel pits) and sorting and processing mineral construction waste. BM "Recycling" produces gravel and mineral aggregates by processing excavated materials with a high gravel content. Both BM sell concrete and gravel, thereby depend on a similar production infrastructure. Along this value chain, extraction and disposal processes are different, whereas the processing of raw materials is rather similar. The access to gravel quarries, being a key resource, is to the extraction business model. Both business models strongly depend on the access to land, either for the storage of material before processing, or for mining purposes.

4.2Business strategies

Along the transition of the BM "extraction" to BM "recycling", two fundamental priorities are identified. BM "extraction" is dominant within the extraction regime, the transitions towards circularity follows societal and political pressure. Mining concessions are granted for a fixed time period, thus the first priority is to extract the available concessions for mining within the granted time frame. Concessions usually run between 5-30 years, this model is calibrated with an average duration of 10 years. Secondly, the existing capacity is utilized and can be used for both, extraction and recycling. Relevant adjustment to machinery is marginal and disregarded in the model. The two competing logics of the business models are (1) to maintain enough concessions to dispose excavation material, and (2) to increase the recycling rate and thereby to reduce the demand for disposal services. BM "extraction" is focussed on the acquisition of further mining concessions, providing the basis for extraction of gravel and disposal of waste management. BM "recycling" focuses on increasing the market acceptance for recycled products.

We find that both BM builds on similar value propositions and value capture, yet fundamentally differ in terms of value creation. On a regional level, the role of the business model "Recycling" as a resource manager becomes significant. Both business models build on similar processes and differ in their raw material supply, sourcing from either gravel pits or construction sites.

4.3 Simulation results

The quantitative model demonstrates the competitive advantage of company A "Extraction", which is largely based on a favourable access to natural resources. As described in section 4.2, access to gravel quarries represents a key resource that defines extraction rates, capacity, processing and disposal capacity. To illustrate this advantage, three policy intervention scenarios are compared.

Table 4 - Scenario description

Scenario	Policy intervention	Duration	Additional changes	Duration
1	Ban land allocations for mining	2020 – 2025	-	
2	Ban land allocations for mining	2020 – 2060	-	
3	Ban land allocations for mining	2020 – 2060	Reduced gravel consumption of 5% per year	2025 - 2035

Scenario 1 and scenario 2 simulate a temporary and a permanent ban on land allocations for mining activities. The respective simulation runs aim at highlighting the dominance of an extraction regime and its potential to transition towards self-sufficient region. Scenario 3 builds on scenario 1 and 2 and integrates a demand perspective, highlighting the role of the regional construction activity.

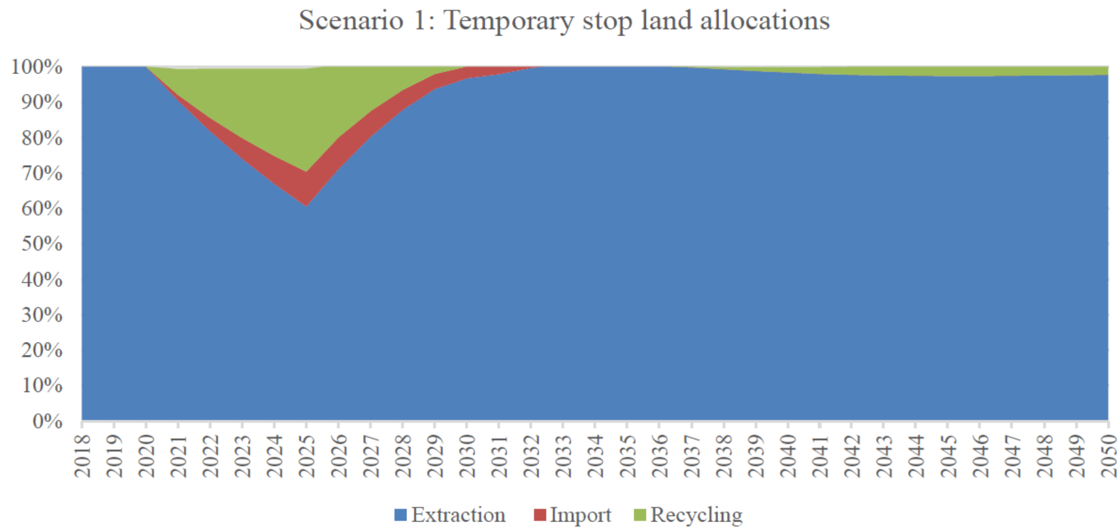

Figure 1: Scenario 1

Figure 1deomonstrates the dominance of the extraction regime, by relating the fractions of extraction, imports and recycling to the total material supply. A temporary ban for land allocations from 2020-2025 increases the recycling rates, along with the import of gravel. After this period, there is a rapid increase of primary gravel extraction that substitutes the competition products. This behaviour can be explained by looking at the dominant business strategies, using existing capacities to extract gravel and secondly employ excess capacities of existing resources to recycle excavation material. The graph shows that mid-2020, demand covered by recycling material peaks. After lifting the ban on land allocations, the respective supply fraction swing back to their original state. This origins from correlation between the mining concessions and the required mining capacity. Adjusting the mining capacity based on granted concessions, falls into a fallacy of ignoring market demand in exchange for access to natural resources. Assuming the granted concessions, exceeds the levels prior to the ban,

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the resulting mining capacity potential exceeds the market demand for gravel. This over capacity is utilized by recycling excavation material and does not increase the rate of extraction. From a socio-technical transitions perspective, this displays dominant constellations of production and consumptions systems that form a regime, resulting from public policies that reinforce rules.

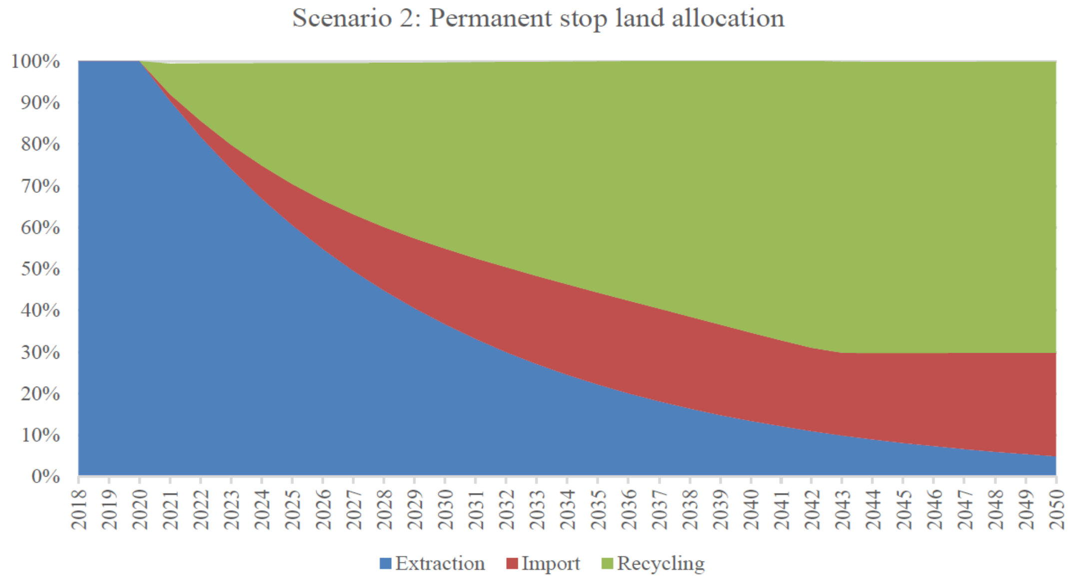

Figure 2: Scenario 2

Figure 2 shows the impact of a permanent stop of allocation land for mining purposes, from year 2020 until the end of the simulation. The system shifts towards alternative production systems, such as recycling and gravel imports. To compensate for phasing out the extraction activities, recycling is significantly increased within 20 years. Recycling then faces a limit to growth, being the availability of excavation material. Without imports of excavation material, the potential of recycling is limited by the availability of local excavation material. The difference between required gravel and locally produced quantities is absorbed by imports. When recycling activities plateau in 2043, the growth of imports continues to rise. Note, recycling of excavation material is capped to a 70% gravel/soil ratio.

This means 30 % of the excavation material need to be either disposed in landfills or alternative recycling products need to be developed. Without a reduction of the total material consumption, a circular economy cannot be achieved due to a lack of secondary resources. These scenarios indicate a fundamental issue ofscale in circular economies

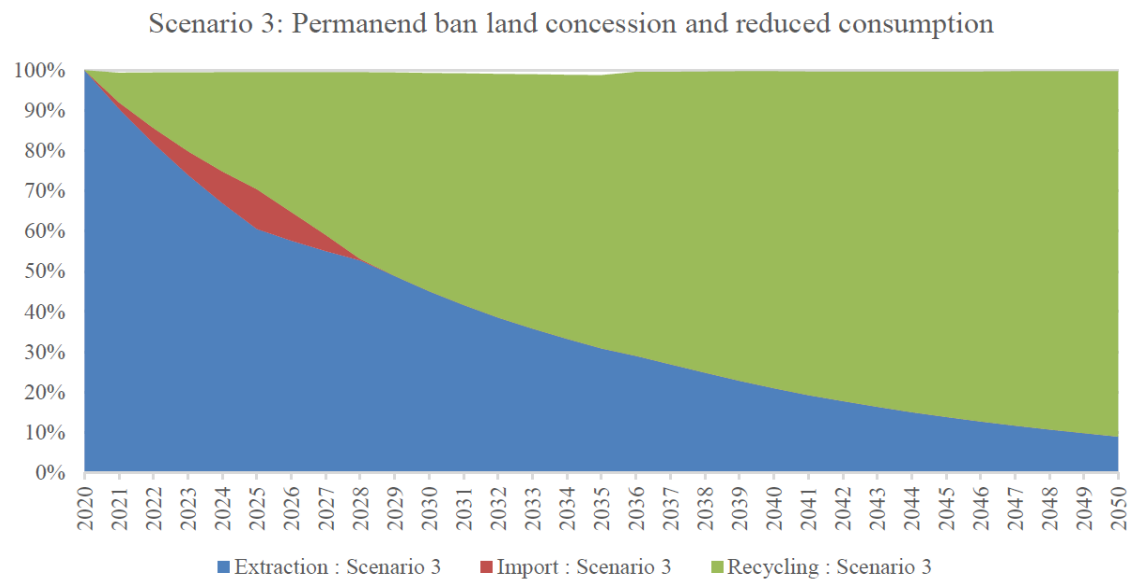

Figure 3: Scenario 3

Scenario 3 simulates a permanent ban on land allocation in combination with an annual 5% reduction of gravel demand between 2020 -2035. Such a reduction could result from changes in the dominance of concrete towards alternative materials. The available excavation material suffices to potentially cover the gravel demand. The dependency on imports to cover the local resource demand diminishes and the region becomes a self-sufficient supplier of raw materials. This scenario points at the duality of socio- technical transitions, requiring changes in technical system coupled to changes in social systems. Without significant reduction in the demand for gravel, the supply of local raw material is not realistic. To achieve a self-sufficient region, the model considers exports. A detailed analysis of scenario 3 highlights the unintended consequences of the ban of mining and reduce gravel consumption. As shown in figure 4, the extraction activities are slowly phased out, along with the uptake of recycling activities. Without mining activities, eventually a lack of disposal volume in the late 2030's forces the region to export excavation material. ALPVAL is independent of raw material supplies, but local disposal volume is insufficient for the disposal of material after the recycling processes.

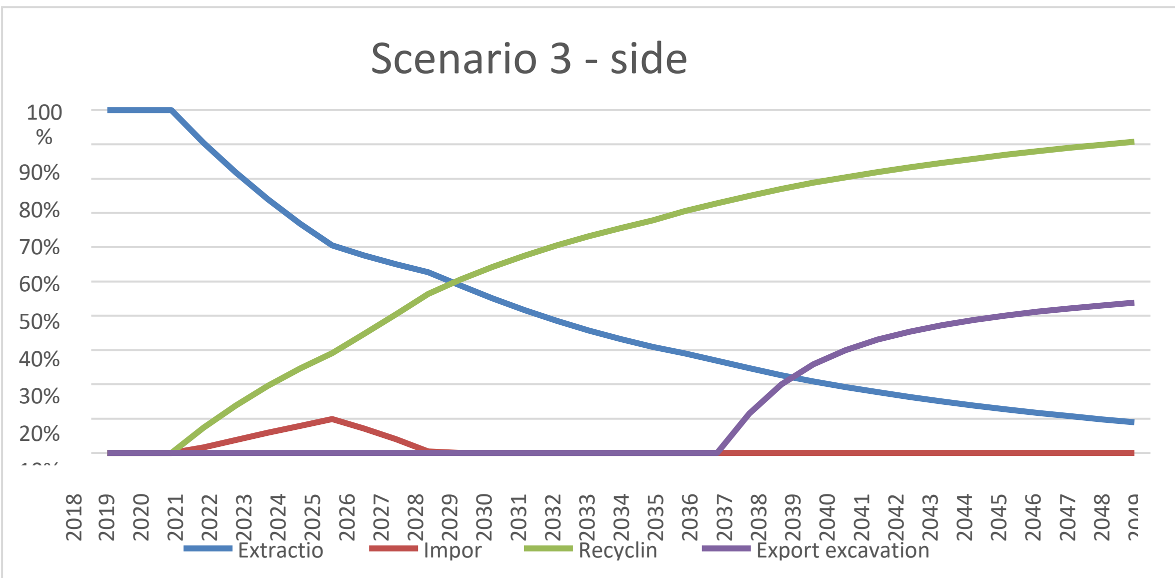

Figure 4: Scenario 3- side effects

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Figure 4 highlights the side effects that accompany the challenges of managing multi-level industry transitions, by looking at the utilization of existing capacities and the decision-making process associated with idealized business models. The simulation shows that recycling activities do not suffice to guarantee the self-sufficient resource management within a region and highlight the role of policy designers to facilitate transitions. The implications of these results are of concern of academics interested in transitions as well as practitioners in policy design.

The simulation model raises questions that address fundamental regime goals, such as the level of construction activity as well as the dominant building design. Connecting material flows to associated business model decisions highlights the dominant logics of a consumption and productions regime. Transitions towards sustainability require adjustments of local business models, but the policy environments needs to facilitate such change.

5. Conclusion

For a transition towards a circular economy in the building materials industry it is essential to identify alternative business models and understand their impact on the production and consumption of primary and secondary resources. In this paper, we identified two business models which, at first glance, seem identical as they produce and sell gravel, but depend on different raw material sources. By investigating these businesses in detail, we wanted to answer the following question:

How can boundary conditions in local markets explain the success of alternative business models and be incentivised by public policies?

For the business models described in this paper, the availability of natural resources is crucial and drives the development towards a circular economy. It is shown that the success of both business model depends on the regional availability of gravel quarries and the possibility to landfill excavated material. Public policies shape the boundary conditions in which business models operate and can play an important role in transition processes. Understanding the role of business models in transitions, helps to anticipate the result of changes in the policy environment, which is simulated with three scenarios. In the simulated land-use policy scenarios, the material flows within regions are altered and conditions for pathways towards circularity emerge. Results indicate that the extraction regime persist if land allocation enables the pursuit of business as usual. Temporary policy interventions do not suffice to enable the diffusion of alternative business models in this simulation. Diffusion of recycling business models only persist of the land allocation for mining purposes is suspended.

Key learnings from the model can be generalized and transferred to other regions, others are bound the idealized region. The transition towards circular business models is in general bound to physical process, hence the limiting factors to recycling is the supply of raw materials. An increasing diversification of companies in waste management does improve the supply chain of individual organizations, but the impact on a region is limited. Without improvements in the utilization of excess products after the recycling process in combination with a reduced consumption of materials, a circular economy provides limited transformative potential. Negative externalities for the local communities appear to be significant in both business models, often resulting in financial compensation. Compensation for the extraction of natural resources has increased the focus on community management to ensure long term access has been observed. In regions with an abundance of natural resources for extraction and disposal, the regime dynamics favour business as usual, whereas urban regions tend to accommodate more recycling businesses. Depending on the regional policy mix for waste management and spatial planning, the dynamics in favour of either regime can vary significantly.

In this paper we compared a traditional, linear business model "Extraction" with a circular business model "Recycling". Building on quantitative data, we demonstrated their impact on a regional scale. It appeared that in terms of value generation, the differences were marginal. These indifferences result from the coupling of value capture and material turnover. A higher material turnover leads to a higher revenue, a logic that is inherently contracting concepts of sustainability in business models. While business models do not fully decouple yet, adjustments to value proposition with additional services such as waste management support the development of a circular economy. While these have not been fully captured in this paper here, further research will detail how circular economy ideas change business models towards more sustainability, and their impact on regional resource consumption, emissions and value added.

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Industrial Experiences with Circular Product Design of Plastic Products

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Abstract

As part of the transition towards a circular economy, improved design of plastic products should lead to higher circularity. The research project 'Circular Plastics' in the North of The Netherlands has a focus on circular product development, next to focus areas on improved mechanical recycling and on chemical recycling of plastics from packaging waste. Several principles are used to reach the objective of higher circularity by better design: reduction of the amount of plastics in the products; transition towards biodegradable plastics; increased use of recycled materials; increased recyclability of the product at the end of its lifetime; new product-service approaches; value chain optimisation for reuse and recycling of products. 15 companies were selected within the region based on their use of specific materials in the products (mainly PET, PE and PP), the volumes of materials used, and/or the focus on the design of products and value chains. The companies vary in size from start-ups to large multinationals. These companies formulated 44 different project questions, of which 18 focused on direct product development, and 10 related to closing the loop from old product to raw material to product again. A selection of 8 projects was made. The selected companies followed a dedicated product development and value chain building approach, depending on the specific needs of each company. Typical project duration was 6-12 months. An analysis framework is proposed to identify the measure of results of the projects as well as the type and principles of the design process. The project team has used dedicated action research approaches directly coupling innovation and research processes in and with the companies. Preliminary results show a high readiness and dedication of most of the companies. Circular product improvements by design are feasible in all selected cases, with a focus on increased use of recycled materials in the (re)designed products. A Materials Circularity Index (MCI) and a simplified Life Cycle Assessment (LCA) tool were used to assess the outputs of the projects. The paper formulates conclusions on the results of the innovation projects, identifies the benefits and shortcoming of the approaches used and looks forward to the next phases of the projects on circular design of plastics.

Keywords: Circular Design, Plastics, Recycling, Value Chain, Life Cycle Assessment

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1.Introduction

The research group circular plastics is part of NHL Stenden University of Applied Sciences, located in the North of the Netherlands. The research group focuses on circular product development next to improved mechanical recycling and chemical recycling of plastics from packaging waste (Crul et al. 2018) (figure 1). Circular product development occurs when plastic materials are reused in new or redesigned products, adding value to the product chain, giving recycled materials a new function with higher durability. In addition, circular product development can mean that new or redesigned products result in better quality and separation of plastic waste, or reduce or prevent the creation of plastic waste.

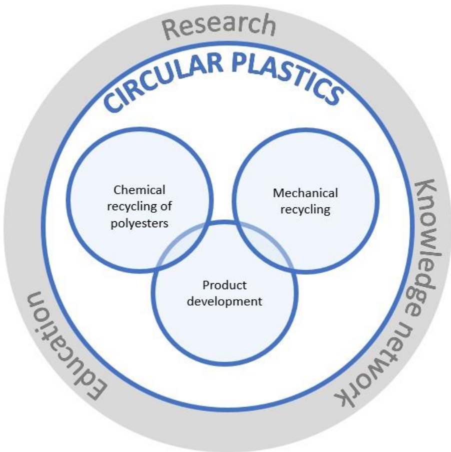

Figure 1. *Research group Circular Plastics with 3 main themes and 3 development goals.*

2. Methods

A first list of 27 companies was made. Companies were contacted by the research group if they were located in the North of the Netherlands and produce plastic products, especially from types of plastics which are also used in the packaging industry, mainly PET, PP and PE. Companies are also contacting the research group themselves. Another route was via contacts of the Circular Economy programme of the regional government. After initial contact, interested companies were visited with a questionnaire related to the transition to circularity of the company and their interest to work with us on this topic. The topics that the companies want to work on with the research group were identified. To select the potential projects, the companies were screened on the following criteria : (1) the company uses the same materials as used in packaging; (2) the question is related to product development; (3) the company has the willingness and right timing to work on this topic. To be selected all three criteria have to be met. Some projects came in later, so they were not taken into this selection process.

The design process of the first batch of eight projects was analysed on two factors: First on the application of design tools during the different design phases (‘understand – ideate – make – validate’), and second on the use of circular design principles. Several principles can be used to reach the objective of higher circularity by better design: (1) reduction of the amount of plastics in the products; (2) transition towards biodegradable plastics; (3) increased use of recycled materials; (4) increased recyclability of the product at the end of its lifetime; (5) new product-service approaches; (6) value chain optimisation for reuse and recycling of products (Ellen MacArthur

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and IDEO 2018).

The estimated output of the projects was calculated with an LCA (Life Cycle Assessment) and MCI (Material Circularity Index) of the product. The LCA was executed by using an online open tool called Ecolizer (Internet source Ecolizer). This is a very simplified LCA tool, for example in the "recycling phase" it does not distinguish between incineration or recycling of the material. In the recycling phase a certain amount of points is given per material type per kg. The transport is not filled in for the projects since the detailing of the concepts was not yet far enough to quantify this. The Material Circularity Indicator (Ellen MacArthur Foundation and Granta Design 2015) assigns a score between 0 and 1 to a product assessing how restorative or linear the flow of the materials for the product, and how long and intensely the product is used compared to similar industry-average products.

To compare the results of the product concepts developed in the projects with the currently used products, 4 ratios for MCI, LCA, plastic recycled content and biodegradable plastic content are calculated.

In the "MCI ratio" the relative difference between the current MCI and the MCI is calculated for the case that the generated concept will be executed according plan, according to the next formula.

$$MCI_{difference} = \frac{MCI_{concept} - MCI_{current}}{MCI_{current}} * 100$$

A positive outcome means the MCI has been increased and vice versa. In the LCA difference the relative difference between the current LCA and the LCA calculated for the generated concept will be calculated according to the next formula. A positive outcome means the LCA has been decreased which means it is a more sustainable product.

$$LCA_{difference} = \frac{LCA_{current} - LCA_{concept}}{LCA_{current}} * 100$$

The difference in use of recycled plastic means the difference between the weight of the recycled plastic the product consists of relative to the total weight of the product in the current situation and in the situation in which the generated concept will be ideally executed as proposed. A positive number means more use of recycled plastics. The formula is described below.

$$Biodegradable\ plastic\ content_{difference} = \frac{Rel.weight\ biodegradable\ plastic\ content_{concept} - Rel.weight\ biodegradable\ plastic\ content_{current}}{Rel.weight\ biodegradable\ plastic\ content_{current}} * 100$$

Where, $Rel.weigth\ biodegradable\ plastic\ content = \frac{biodegradable\ plastic\ content\ weight}{total\ product\ weight} * 100$

The difference in use of the biodegradable plastics means the difference of the weight of the recycled plastic of which the product consists relative to the total weight of the product between the current situation and the situation of the new concept. The formula is given below.

3. Results and Discussion

Company and project selection

Of the 27 contacted companies 15 companies formulated research questions related to product development.

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Two companies said they were not interested in the topic. Another reason mentioned for not working on circular product development was bad timing for the company. For two companies, the questions they had could not be dealt with in our research group (see figure 2). Mentioned reasons to work on the topic were (1) requests of customers to increase the recycled content; (2) the drive of the company to become a more sustainable company, related to the negative image of plastics; (3) marketing driven reasons. From these companies we got 44 different project questions. From these 44 different questions 18 are directly related to product development, 10 were related to closing the loop from old product to raw material to product again, six are related to development of a system or value chain, two are related to the sourcing of recycled material of the right quality, and nine are related to recycling questions, for instance 'how is it technically possible to recycle my product' (see figure 3). When the topic the company raised was not related to circular product development, but materials characteristics/ recycling only, it was passed to other researchers of the group. The readiness and dedication to work on circularity can be described as high for a majority of the companies (see figure 4).

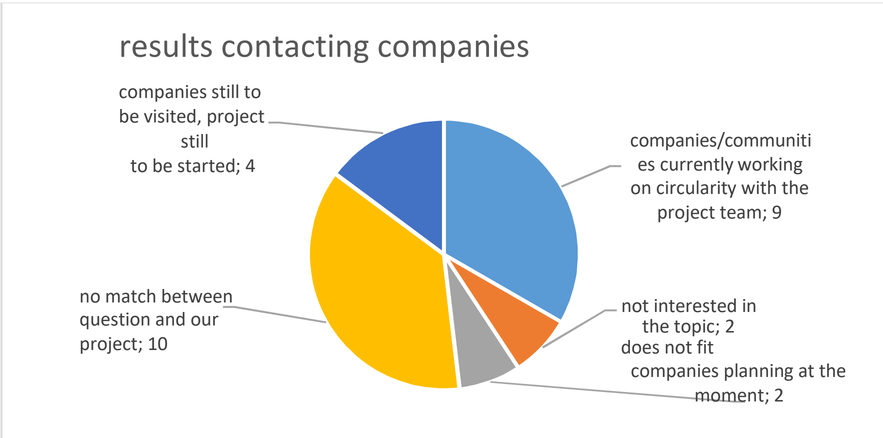

Figure 2. *Results of contacting companies.*

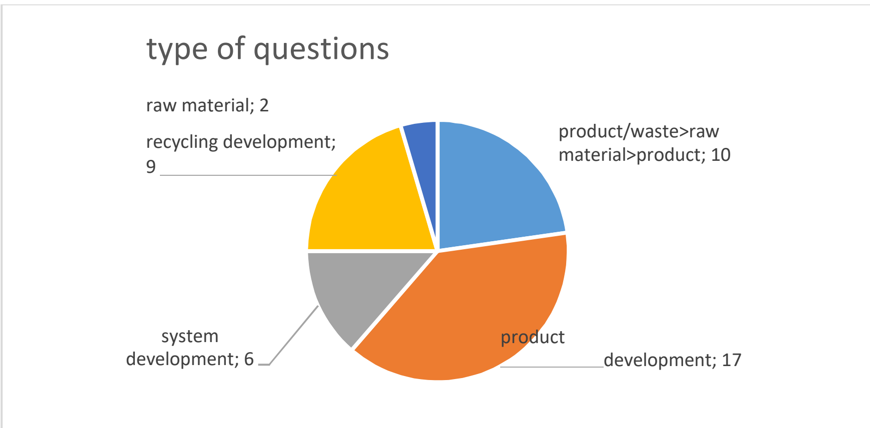

Figure 3. *type of questions from the companies that are willing to work on circularity.*

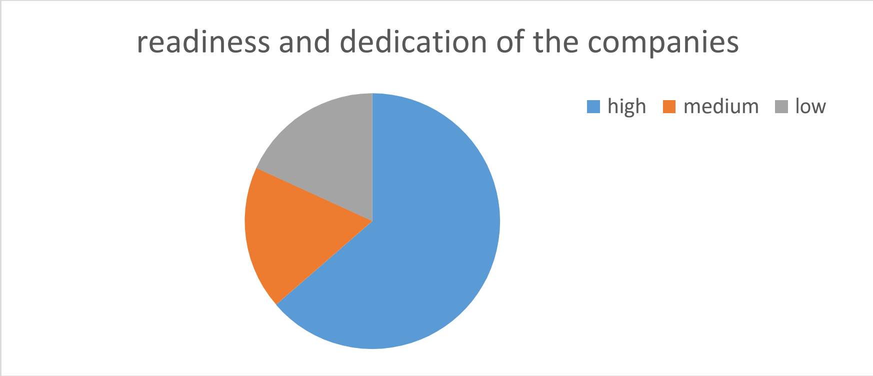

Figure 4. *Readiness and dedication of the companie*

The 27 companies contacted were screened following the process as described in section 1, looking into the materials used, focus on product development and willingness and right timing. This process delivered a selection of eight projects at seven companies that were executed (table 1). The producer of large plastic products has two projects.

company	type of material	type of question	timing	selected
flag producer	V	V	V	V
cable producer	V	X	V	
company for outdoor tiles	V	X	X	
brush producer	V	V	V	V
Producer large plastic products	V	V	V	V
coffee and water cup service	V	V	V	V
foil packaging producer	V	X	V	
consumer products company	V	X	V	
packaging producer	V	X	V	
locker producer	X	X	X	
transport company	X	X	V	
mycelium plates producer	V	V	X	
printing company	V	X	V	
cabinet maker	V	X	V	
office furniture refurbisher	V	X	V	
dairy drinks company	V	V	V	V
pipe producer	V	V	X	
foam panel producer	X	X	V	
Building company	V	X	V	
Infrastructure company	V	V	X	
biocomposite profiles comp.	V	V	V	V
city grower	V	V	X	
social working place company	V	V	X	

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waste stream manager	V	V	X	
community plastic free	V	V	X	
community clean sea	V	V	X	
facility management NHL Stenden	V	V	V	V

Table 1. *Screening of the projects.*

Design Projects

The following eight projects were executed (Also see table 2):

The *Producer of large plastic products of recycled plastics* makes products from their own specified types of recycled plastic and with their own injection molding techniques for massive plastic products, techniques not belonging to standard plastic processing techniques (Koster and Ogink, 2005). In their portfolio are products like poles, planks, sheet piles, water side facings, scaffoldings, bridges. The company is looking for opportunities to expand their portfolio to increase their sales. Based on an extensive market analysis and design project (Nylund et al. 2018), a modular system for an outdoor chair was developed (project 1). To accelerate the closing of the loops, a cooperation between a waste processor company and the research group, a project was performed. Goal of the research is to investigate the possibilities of the use of LDPE plastic granulate, originating from household foils provided by the waste processor company, as feedstock for this new product. A second project for this company is a new product concept for dragline plates, after a first term a second loop was made for further engineering of the dragline plates (Tolsma 2018) (project 2). Circular development principle used was "increased use of recycled materials". There is a large improvement in the MCI in the use of recycled plastic, while it is not an activity of this company to have a collecting system for wasted dragline plates. If the wasted dragline plates are recycled, the MCI will increase even more compared to the existing dragline plates. The Ecolizer is less reliable when working with recycled materials like the material used by this company.

The *Dairy drinks company* is a large international company. Since the product itself has a relative big footprint related to other type of drinks and consumables, there is a focus to lower the footprint of the agricultural part of the lifecycle. Since a few years awareness about the environmental impact of the packaging has increased. Currently about 50% recycled PET is used to bottle their products. The objective of our research project is to use 100% recycled PET (Tazoe et al. 2019). The company experiences a shortage of (r)PET on the market. To reach the objective the company itself needs to work on the circularity of their packaging to get back the wasted PET bottles (project 3). In order to retrieve all the (r)PET necessary to solely produce recycled bottled products, and eventually become circular, consumer behavior and the recycling systems are investigated. The small PET bottles will get a QR code referring to a website with information about recycling of this particular bottle.

The *Bio-composite profiles company* is a start-up with strong links to a building and construction company. The company sells construction profiles which are extruded from bio-composite material which is a good replacement for wood. The advantage compared to wood is that it can be used outdoors without any maintenance and the construction can be lighter since the profiles can be hollow. The company is investigating an alternative construction for solar panel arrays without using the standard metal tubes and profiles. The base of the bio- composite profiles is produced with connectors and anchors of recycled plastics. In our project this construction is calculated so the optimal composite profiles could be chosen. Also, concepts are made for the connectors and anchors. Post-consumer plastic waste is taken as raw material (project 4). When comparing the existing anchor from galvanized metal to the plastic version the environmental impact of the plastic version, the plastic version is 20% better when analyzed in Ecolizer. The recycling of the plastic version has a better score compared to the recycling of the steel version, even with a weight increase of the plastic version of about 40%. The freedom of shape is bigger because the production process is injection moulding. The chosen shape will reduce the amount of rejects during the placement of the anchors. It is estimated that the MCI can increase by 25% due to the high amount of recycled feedstock in the plastic version and a lower reject rate. A producer for these plastic products is contacted. The next phase will be further engineering of these plastic parts and developing the material recycling process in the mechanical recycle lab.

The *Facility management department of NHL Stenden University* helps to organise and execute logistic and in- house activities like supply, storage, distribution of goods, cleaning and maintenance, organising the waste streams. The department formulated a goal to increase the circularity within NHL Stenden University. With 1700 employees and 25.000 students this can create a high impact. To create more awareness on the NHL Stenden University the project was formulated to create a product out of the plastic waste from the University (project 5). The plastic waste was sorted and analysed. PET, mainly coming from small bottles, turned out to be more than 20% of the weight of the waste plastics. Questionnaires, brainstorms and research on existing products were done together with students to generate different concepts (Hubach 2019). The selected product concept was a modular bench in the shape of a bottle made out of recycled PET. The bench is constructed out of 3D printed segments. The bench will initially grow by the continuous stream of waste PET. When awareness grows because of the communication connected to the project, PET waste generation at the University is envisioned to reduce and the bench will finally shrink when segments become obsolete and no new segments are produced. For the MCI and the LCA one seating segment of the bench is compared with an existing bench also made from wasted packaging plastic (Internet reference Eco-oh). This bench is produced by injection moulding and commercially available. It can be expected this product is more extensively tested and engineered compared to the concept of the new concept of the bench at NHL Stenden.

The *Coffee and water cup service* offers coffee and water cups including a recycling system. Used cups are put in a special recycle box. When picking up the full boxes a new supply of cups is delivered at the same time. The used cups are mechanically recycled and used for products like plant trays and clothing hangers. The coffee and water cup service will be based on a new cup made of biobased and biodegradable plastic PHBV. An international student group of a related project, Circular Design (De Eyto et al. 2018), has developed a system for the value creation, logistic system and user experience of this cup on festivals (Berglund et al. 2018).To enhance this system a new product was created and further elaborated during a brain storming session (project 6). Next to the substitution to biodegradable materials, a key circular design principle was the increase use of recycled materials. In the LCA and MCI calculation the new biodegradable

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festival cup is compared to the standard used cup. The water consumption for cleaning the biodegradable cup is not taken into account since this is not possible in the Ecolizer tool.

The *Flag producer* is very motivated to make a circular flag. The company sells flags made from recycled PET. The graphics are produced by screen printing technics or digital printing. Different types of flags are sold. Beside an investigation on chemical recycling of the flag fabric for materials suitable for yarns, a logistic system has to be developed and the flag itself needs to be better recyclable. To make the flag suitable for recycling an overview of the different parts and materials of the different types of flags is given. It is proposed to make all parts out of the same material, so no disassembly is needed (project 7). Circular development principle: Increase the recyclability of a product at end of lifetime. In the MCI and LCA a comparison is made between a flag from virgin material to a flag that is collected and recycled into new flags.

The *Brush producer* wants to use the waste from their production process to produce a handgrip for a brush by 3D printing. Their waste consists of LDPE foils and cutting waste from PP and Polyester brush hairs. Trials to produce filament from the waste of the brush hairs show that the material was too much mixed to produce good filament. There is also the question how to shredder these hairs, since they are too small for the normal shredder, but too long for the filament extruder. The next step is to produce the handgrip by a hand-pulled ejection machine, the first tests look promising (project 8). Circular development principle: increase use of recycled materials. In the MCI and LCA calculation a brush with a self-produced handgrip from their production waste material is compared to a brush with a standard purchased handgrip made from virgin material of the same type of plastic. The projects are summarized in table 2.

To describe what design processes were applied, first the design tools used per design phase are presented in table 4 For many projects, tools from the Circular Design Guide (Ellen MacArthur and IDEO 2018) were used. In project 1 and project 6, four design iterations were made. Both were project executed by student groups from Circular Design project, in which a dedicated multi-loop approach was used. The tools presented are a summary of all four loops.

Table 2. *Overview of the projects.*

project	**company**	**short description of the company**	**project question**	**type of material**	**material volume/year**
project 1	producer of large plastic products	big company situated in more locations over the world having their own specialized production technique	what are opportunities to expand their portfolio to increase their sales?	recycled LDPE and PA according their own specs.	large

project 2	same as project 1	same as project 1	development of a new product concept for dragline plates	same as project 1	same as project 1
project 3	dairy drinks company	multinational company producing daily dairy products, like milk and yoghurt drinks	investigation of consumer behavior and the recycling systems to retrieve the small bottles back for recycling.	PET	large
project 4	biocomposite profiles company	start up with the ambition to combine bio composite profiles with parts from recycled plastic	Investigation of an alternative construction for solar panel arrays without using the standard metal tubes and profiles	PP/PE	medium
project 5	Facility management of NHL Stenden University	facility service of a big university of applied science	How can we increase the awareness of students and employees about the amount of single used plastics on our school?	PE, PP, PET	medium
project 6	coffee and water cup service	A small company delivering a service of coffee and water cups of PS which also can be returned after use and will be recycled into new products like plant trays and clothing hangers.	development of a value system around a biodegradable cup on festivals.	PHBV	Medium
project 7	flag producer	A medium big company which sells flags. The fabric is printed and a flag is made of it.	redesign of a flag to make it suitable for recycling	PET	medium

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project 8	brush producer	small company which assembles hairs on handgrips/holders for brushes.	how can a handgrip of a brush be made by our production waste by ourselves?	PA, PE, PP	small

Table 3. *Overview of the design tools used per design phase*

project	UNDERSTAND	IDEATE	MAKE	VALIDATE
1	PESTEL analyses, survey, on site research, expert consultation, stakeholder analyses, SWOT analyses, sustainability diagram, distopia/utopia mapping, business model canvas	brainstorming, sketching	rapid prototyping, personas, story boards, actors map	weighted objectives. Prototype user testing.
2	material research, life cycle journey, business model canvas, QFD model, concept selection via Kesselring method	idea generation, morphological overview	detailed concept design, 3d modelling	calculation of CO2 footprint, cost price calculation
3	literature review, expert interviews, persona canvas, customer empathy mapping, consumer questionnaire, context map canvas (mixture of Porters Five Forces and PESTLE analysis), research question brainstorming	fresh watching, research questions brainstorming, value proposition design, SWOT analyses	using epicenter method, business model canvas	customer interviews, business model design questions
4	expert consultations, desk research	sketching, brainstorming	3d modelling, 2d drawing	LCA, FEM calculations
5	resources flow analyses, interviews, shadowing/ observations, questionnaire, customer journey, mood boards, Okala Ecodesign Wheel, MoSCoW method.	sketching, Brainstorming: x-3- 5, ABC-zinnen, mindmapping, brainwriting, Harris profile	rapid prototyping, Business Model Canvas	questionnaires, user tests

6	value chain mapping PESTEL analyses,lean canvas, actor mapping, value chain mapping	vision definition by utopia and dystopia methode, product system service mapping, circular business model canvas, brainstorming, mind mapping	rapid prototyping, sketching, concepting, requirement value matrix	interviews,in field user testing,
7	expert consultations, on site research, LCA and MCI calculation	brainstorming	concepting	cost calculation, KCA and MCI calculation
8	material analyzes	sketching	rapid prototyping	stakeholder interview

Next, the projects were analysed for application of the key design principles as formulated in section 1. The most important circular design principles used in each project were identified (see Table 4). In most projects 'increased use of recycled materials' was the dominant principle.

Table 4. *Overview of the circular design principles per project.*

	circular product development principles
project 1	increase use of recycled materials
project 2	increase use of recycled materials; value chain optimization for recycling.
project 3	increased use of recycled materials; value chain optimization for recycling
project 4	increased use of recycled materials
project 5	increased use of recycled materials
project 6	substitution to biodegradable materials increased use of recycled materials
project 7	increased recyclability at the end of the lifetime; new product-service approach.
project 8	increased use of recycled materials

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Project Outputs

For each project, the estimated output per project is presented for MCI difference, LCA difference and Difference in use of recycled plastic (see figure 5). Specifically for the use of biodegradable plastics of the coffee and water cup producer (project 6) the difference in use of biodegradable plastic content is presented instead.

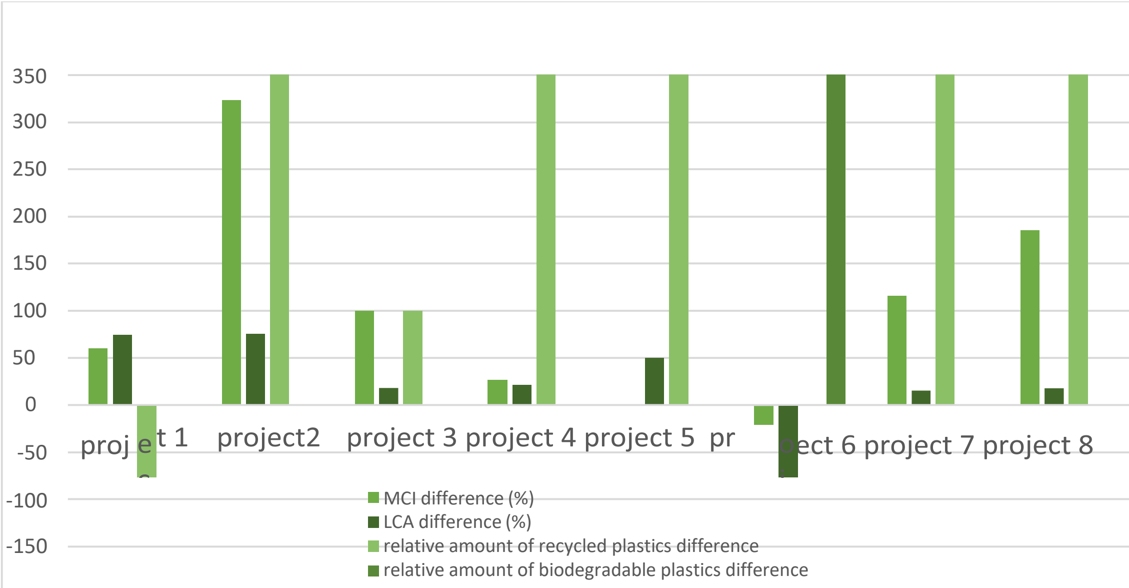

Figure 5. *Project indicators per project*

Overall, the projects show a positive score in both the MCI and in the LCA difference scores.

Five projects score infinite on the indicator Difference in use of recycled plastic. In the current situation recycled plastic is not used at all for the Soil Anchor project, the Soil Plate project, the brush project and the Flag project. The concept there is to substitute wood and steel for plastic. In the flag project the starting point was that the non- recycled PET flags will be replaced by recycled PET material. Also there the current situation is taken as zero recycled plastic content.

The relative amount of recycled plastic difference gives a negative result for project 1. In the new design of the outdoor furniture the base of the construction is made of concrete which makes up for a relatively big amount of the total product weight. Although concrete is a material which can be recycled, the indicator "relative amount of recycled plastic" is less compared to the current situation where an outdoor bench is almost completely made of recycled plastic (Internet source Eco-oh).

The biodegradable cup project (6) is the only project with a negative LCA and MCI and has a positive Difference in use of biodegradable plastic. This project's most important aim was to go for biodegradable plastic and since this is a food application it is not possible to reuse the biodegradable plastic in the cups again, but only in a side product (cupholder) where the used amounts are much lower. The comparison between the LCA and MCI of a standard festival cup, which is non-biodegradable and the biodegradable festival cup gives a lower score for the biodegradable cup. This is why the Differences for both indexes are negative.

In all cases MCI difference and LCA difference outputs are pointing in the same direction, both positive or negative. For the Awareness project there is no difference on the MCI score since for the reference product (current situation) an example product is taken which is also made completely from recycled household waste plastic. Both have a comparable result in the calculations. That is also the reason to take this as the reference product in the LCA. The champion in the LCA score is the dragline plate project (2). The recycled content of the plates is increased, and the lifetime is doubled.

4. Conclusions

Most of the companies contacted have a positive attitude towards circular product development for customer demand, marketing or sustainability reasons. This is confirmed by the high level of interest for the topic and the dedication to work on it that was reported. This shows the topic is relevant for them and the project interventions timely. However, a certain bias can occur here since many of the companies were already in the network of the research group or partner in the regional circular economy programme. So this conclusion is not valid for a random group of similar companies. The inventory of the type of questions relevant for the companies show a prevalence for actual new product (re)design initiatives as well as projects aimed at the closing the material loop from product to raw material to product.

The actual design projects executed show a large variation of topics and innovations that were dealt with in line with the variation of company types and sectors. The design processes applied show a focus on tools and activities in the first ‘Understand’ phase, showing that the topic of Circular Design is new for most participants. Also, the use of MCI and LCA tools to estimate the output of the project was new for most of the companies, especially for the small and medium sized companies. The dominant circular design principle applied in most of the projects, increased use of recycled materials, is believed to be one of the easier approaches for companies to start with circular design. The design of the product remains unchanged and the effect on customer experience, markets and production processes is limited. Most changes will appear in the supply chain of the company. It is too early to provide results about the total increase in the application of recycled materials. Most of the projects are in a concept phase. More detailed engineering and finally data on the actual sales are needed to estimate this.

The MCI and LCA calculations of the (re)designed products mostly show positive scores, which indicates the overall objective of the projects to develop more circular products has been successfully achieved. The MCI is calculated in an early stage of the development process to be able to communicate to the company what the impact of the project could be. Therefore, the calculations are based on several assumptions. Updating these calculations with more detailed data will provide more insight for the companies in later phases but was not done during the project. The MCI score is seen as a simple, one-dimensional score that will help awareness and dedication of the company in the start phase of circular projects. Communication of more complex LCA results is more useful in later phases, when specific decisions that can lead to trade-offs in environmental impact have to be made.

Although the use of the Ecolizer LCA tool gives a first estimation of the environmental impact, we found the tool to be very limited specifically to analyse circular design projects in a satisfactory way. These limitations have been described in this paper as much as possible. For instance, good data for recycled plastics are not available. Also, for the Ecolizer program there is no difference whether the materials come from own sourcing, like waste from production, or is a material bought from a general supplier. The MCI on product level does not take into account whether the waste of a product is used as a recycled material in the same or a different product. Also, the MCI does not look to the total amount of materials used in one

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product. When the total weight of a comparable product is much lower, but the recycled content less, the one with the higher weight gets a better score. However, time and capacity to deploy more comprehensive tools (see for instance Goedkoop, 2013) in the beginning of the projects was not available.

For the future company projects of our research programme, the emphasis will be shifted towards other, more innovative circular design principles than increased use of recycled materials. We intend to do more work on reduction of materials used and on reuse of the products, since these approaches are generally preferable over just more recycling of materials and will have a better overall effect on impact reduction.

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Consumer perceptions of remanufactured automotive parts and policy implications for transitioning to a circular economy in Sweden

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Abstract

Promoting longer lifetimes and efficient re-use of products has a significant potential to save resources and reduce adverse environmental impacts, especially for products that have large resource footprints related to extraction and production processes, as for instance automobiles. Remanufacturing is a product life extension strategy promoting the effective and efficient re-use of products by replacing worn-out components with used or end-of- life parts that have been restored to "like-new" condition and functionality. For the development and upscale of remanufacturing processes it is important to consider consumers' perception of remanufactured products, as well as supply-side factors such as technology and operations management. Previous research has concluded that perceptions of a certain product or service constitute a critical factor in the consumers' decision-making process. However, there is a lack of studies that explore consumers' perceptions of remanufactured parts, especially in Europe. This contribution analyses the results of an on-line survey (n=203) of Swedish consumers, concerning their knowledge of remanufactured auto parts and their perceptions on associated benefits and risks. The survey revealed that Swedish consumers have limited knowledge about remanufactured products. On the other hand, they do recognise the benefits of using such parts without showing a significant risk aversion in their purchase decision of remanufactured auto parts. The survey also explored consumers opinion on potential measures to bridge the identified gap in knowledge, revealing that although they would trust a quality certification scheme for remanufactured auto parts – preferably set up by an industry association – that would not be the most critical factor in their purchase decision. Concluding, the article points out the potential of policy interventions to raise consumers' perceptions of remanufactured parts to create a market pull for expanding their uptake, and thus increasing the overall resource efficiency in the automotive sector.

Keywords: Remanufacturing, Circular Economy, Consumer Perceptions, Resource Efficiency, Policy.

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1. Introduction

An increasingly expanding global economy, sustained by high consumption levels both in developed and emerging economies, raises concerns over the detrimental exploitation of the earth's natural resources, coupled with associated environmental impacts and impending resource shortages (Beylot et al., 2019; Hashimoto et al., 2012; Wiedmann et al., 2013). In response, several governmental and supra-governmental initiatives have taken form over the last decades with the aim to increase resource efficiency in the economy and reduce adverse environmental and socio-economic impacts (Flynn and Hacking, 2019; McDowall et al., 2017). In Europe, there is a growing political consensus in the European Union (EU) to move away from the current resource intensive "linear" economic system, towards an innovative system aiming at closing material loops – the so-called circular economy. The introduction of new policies targeting all stages of the life-cycle of a product are needed to facilitate the transition to a circular economy in Europe (Domenech and Bahn-Walkowiak, 2019; Milios, 2018). While current waste management policies have shown some success in increasing the circulation of materials in the economy (EEA, 2013), a major challenge remaining to be addressed is to preserve the functionality and economic value of products and components and not just recovering their materials at the end-of-life (IRP, 2018).

Remanufacturing is an industrial process through which used or end-of-life products gain a second useful life retaining the same quality, functionality and warranty as new products (Lund, 1984). Benefits of remanufacturing are the lower price of products, the avoidance of raw material extraction for production and job creation, as remanufacturing is typically a labour intensive activity (Matsumoto et al., 2016). Additionally, remanufacturing contributes to the prevention of waste generation, promotion of environmental consciousness and conservation of energy (McConocha and Speh, 1991). A study by Kim et al. (2008) showed that a remanufactured alternator requires one-fifth of the material and one-seventh the energy consumption of a newly manufactured product. A wide variety of barriers to effective remanufacturing operations have been identified in literature, e.g. uncertainties regarding availability and quality of cores, misperception of component quality, international trade barriers etc. – and recommendations have been drawn for policymakers, researchers and industry to overcome these barriers (Karvonen et al., 2017). One of the main barriers is associated with wider market formation, which implies the size of market and demand for remanufactured products and/or components. Directly connected to market formation is consumers' acceptance, preference and purchase intention of remanufactured products (Kalverkamp and Raabe, 2018).

The objective of the present study is to investigate consumers' perceptions in Sweden regarding remanufactured automotive parts. Despite widespread remanufacturing activities globally, research examining consumers' perceptions of remanufactured products remained limited until recently (Abbey et al., 2015; Gaur et al., 2015; Jimenez-Parra et al., 2014; Matsumoto et al., 2017; Michaud and Llerena, 2011; Wang et al., 2013). In the past few years, however, researchers have recognised how consumers' perceptions of remanufactured products affect their behaviour and can influence their purchasing decision. Perception is the way people can understand their surroundings. Peoples' attitudes and actions towards an object are highly conditioned by how they perceive things (Matsumoto et al., 2017). This contribution follows closely the extensive investigation of consumers' perceptions of remanufactured auto parts by Matsumoto et al. (2017, 2018a, 2018b), and applies their established methodology in an effort to uncover relevant findings in a European context. Previous studies by

Matsumoto et al. (2017, 2018a, 2018b) have focused in US and Asian markets, but the European perspective is still missing from similar literature regarding remanufactured auto parts.

The choice to focus on remanufactured automotive parts is considered for a variety of reasons. The automotive industry is chosen for its long history of remanufacturing, being the largest remanufacturing sector worldwide, accounting for an estimated two-thirds of global remanufacturing activities (USITC, 2012). On the one side, cars contain high value and durable components and on the other side the co-existence of first- and second-hand markets for auto parts eases the re-use of parts and makes it readily available to customers. Various automotive components have high potential for remanufacturing (Steinhiper and Nagel, 2017), and therefore a great potential for resource efficiency and energy savings exists in the process of auto parts remanufacturing.

Sweden is selected as a case study due to its clustered remanufacturing industry, mainly connected to major original equipment manufacturers (OEMs) in the automotive sector. The largest car manufacturer in Sweden reports that their remanufacturing operations currently covers 15 percent of vehicle spare parts supply. Due to decreased raw material extraction and energy used for remanufacturing compared to new production, the remanufacturing of spare parts saved 542 tonnes of steel and 265 tonnes of aluminium in 2017; this corresponds to nearly 3,000 tonnes of carbon dioxide emission reduction (Volvo Car Group, 2017). Due to these reported benefits, OEMs in Sweden are keen to expand their operations and increase remanufacturing activities, however, an important aspect that needs to be taken into consideration is the consumers' perception.

This contribution aims to generate new knowledge that responds to industry concerns over consumers' acceptance and purchase intention of remanufactured auto parts and propose ways to increase confidence and potentially market share of remanufactured over new components. The remainder of this article is organised as follows. In Section 2, the theoretical underpinnings of this investigation are fleshed out, briefly determining the factors that affect consumers' purchase intentions and the influence of information provision and quality certification. Section 3 details the applied methodology and Section 4 presents the results and discusses the findings. Finally, Section 5 contains the conclusions of this study with a number of recommendations for future research.

2. Consumer perceptions of remanufactured products

Although, remanufacturing has the potential to induce higher resource efficiency in the manufacturing sector (IPR, 2018), especially within the circular economy paradigm (Milios, 2018), there is still considerable consumer resistance to buying remanufactured products (Abbey et al., 2015; Hazen et al., 2017). Consumers often have the perception that these products have a lower quality than the equivalent new ones (Abbey et al., 2017; Guiot and Roux, 2010; Hazen et al., 2017). The lower price of second-hand goods has been traditionally associated with making up for the perceived lower quality of a product, and thus increasing the attractiveness of remanufactured goods (Debo et al., 2005). This, in turn, spurred a substantial amount of research dedicated to the optimal pricing of these products (Ovchinnikov 2011). However, significantly less research has been dedicated to the actual knowledge and characteristics of such products by consumers to ameliorate their purchasing decision, other than optimal pricing. Knowledgeable consumers can relatively easy comprehend that the quality and performance of remanufactured products is equal to new products (Hauser and Lund, 2003), while consumers who lack knowledge of remanufactured product quality are more likely to buy new products

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(Ferrer and Whybark, 2000).

2.1 Product knowledge

Consumers' product knowledge can directly influence their evaluation criterion for a given product (Barrutia and Gilsanz, 2013), thus further influencing their purchasing behaviour (Matsumoto et al., 2017). In a previous study, Matsumoto et al. (2017) found that 80% of US consumers have heard about the existence of remanufactured auto parts, whereas only 20% of Japanese consumers have been familiar with the term "remanufactured auto parts". Hazen et al. (2012) found a relationship between the consumers' "tolerance for ambiguity", i.e., tolerance of the absence of information required to understand a situation (in this case, the remanufacturing processes and product properties) and their willingness to pay for remanufactured products, which indicates that knowledge of the product or process leads to higher purchase intention of a remanufactured product. Additionally, the tolerance of ambiguity is related to perceived quality, which in turn is related to the willingness to pay (Hazen et al., 2012).

2.2 Perceived risks and benefits of remanufactured products

Consumers' willingness to pay for remanufactured products differentiates with regard to the perceived risk that the products are of lesser quality, either functionally or cosmetically (Abbey et al., 2017). Abbey et al. (2017) identify lifespan, features, performance, and serviceability as important underlying factor of consumers' perceived quality of remanufactured products. Guiot and Roux (2010) found that consumers perceive a high risk when buying certain types of second-hand products such as household appliances, computers, televisions, and audio equipment. One cause behind this is suggested to be the inconsistent claims from sellers. Guiot and Roux (2010) advocate for the need of guarantees (i.e., warranties) and technical documentation. Wang et al. (2013) investigated Chinese consumers' purchases of remanufactured auto products and identified five dimensions of risk: performance, time, physical, financial, social, and resource risk. Consumers' concern over lower-quality of remanufactured products is one reason leading to lower acceptance and willingness to buy such products, and ultimately constitutes a major barrier in increasing their market share (Hamzaoui-Essoussi and Linton, 2010; Harms and Linton, 2015; Michaud and Llerena, 2011). Uncertainty is considered an important inhibitor of the purchase of remanufactured products (Peter and Ryan, 1976).

On the other hand, several perceived benefits of buying remanufactured products could turn consumers into adjusting their purchase preferences. As mentioned already, benefits of remanufacturing include savings in labour, material, and energy costs, shorter production lead times, balanced production lines, market development opportunities, and a socially positive image (Matsumoto et al., 2018a).

2.3 Purchase intention

In this study, we examine how underlying factors, such as consumer knowledge of remanufactured auto parts, benefit and risk perceptions influence the behavioural intentions of consumers in Sweden. Previous studies have concluded that purchase intention is directly influenced by consumers' perceived risk, perceived benefit, and knowledge of remanufactured products (Matsumoto et al., 2017, 2018a; Wang et al., 2013). If consumers are knowledgeable of the benefits of remanufactured products, then they understand the cost-benefit of purchasing remanufactured better than those who are less knowledgeable (Hamzaoui-Essoussi and Linton, 2014). Therefore, we are testing the following three hypotheses:

H1. Product knowledge positively influences the purchase intention of remanufactured auto parts.

H2. Perceived benefits positively influence the purchase intention of remanufactured auto parts.

H3. Perceived risks negatively influence the purchase intention of remanufactured auto parts.

2.4 Quality certification

Product eco-labelling, quality certifications, standards, and other relevant information tools are considered as promising means to assist consumers in their decision-making process (Thøgersen, 2005). Despite the documented potential of labelling and certification schemes to inform consumers, sociological and environmental studies have demonstrated that just provision of information does not necessarily lead to changes in attitudes, and even when it does, the change does not always translate into behaviour change (Mont and Power, 2010). However, in the case of remanufactured auto parts, a reliable quality certification constitutes a critical factor in decision-making because consumers cannot verify the quality of remanufactured products before purchase, contributing to a higher risk perception (Michaud and Llenera, 2011). Credible quality certifications can provide consumers with direct signals of product quality, and thus they can help reduce consumers' perceived risks of remanufactured products (Michaud and Llenera 2011; Wang et al. 2013). Therefore, in this study we additionally explore the influence that information provision and quality certification of remanufactured auto parts exerts on the purchase intention of Swedish consumers. Furthermore, we identify which certification issuing agency consumers would be more likely to trust for making better informed purchasing decisions.

3. Method

This study investigates how factors such as consumer knowledge of remanufactured auto parts, as well as benefit and risk perceptions affect the purchasing intentions of consumers. The method used in this article follows closely the methodology outlined in previous studies by Matsumoto et al. (2017, 2018a, 2018b), exploring similar aspects of consumers' perceptions in the markets of U.S.A., Japan, Malaysia, Thailand and Vietnam. The method is constituted by an on-line survey and the statistical analysis of the results. For the current study, we chose to perform a survey about the knowledge, benefit and risk perceptions of a remanufactured gearbox. The selection of this remanufactured auto part, in contrast to the previous studies where alternators and starters have been investigated, is due to the existing remanufacturing operations and market share of this part in the Swedish market

– directly in connection of operations by the leading OEM in Sweden. Since the remanufacturing and marketing of this spare part is already taking place in the domestic market, it was selected as an appropriate case, since the probability of consumer knowledge might be significant in relation to other non-wide-spread auto parts. This poses a limitation in the study, since the sample entails non-probability aspects. However, the sample would be more representative for the purpose of this specific study.

3.1 Survey

The survey consisted of three sections. The first section asked for general characteristics of the sample

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population, including three introductory questions on their relative knowledge of repairing and the option of remanufacturing alternatives. The second section consisted of 14 questions about knowledge, benefits and risks of purchasing a remanufactured gearbox. The third section included questions about the influence of product information and quality certification of a remanufactured gearbox in consumers' purchase intention. The sample was between 18 and 74 years old. The selection criteria of the sample population included that each respondent owns at least one car and is its primary driver. Full profile information of the respondents is provided in the Appendix (Table A.1).

3.2 Dependent and independent variables

The dependent variable in this study is the 'Purchase Intention'. Purchase intention is defined as "(the) individual assessment of future willingness to buy" (Wang et al., 2013). The principal objective of this study is to investigate how the different elements of consumers' perceptions (independent variables) influence the consumers' purchase intention.

Consumers' perceptions about a remanufactured gearbox are measured by their responses to 14 questions on a seven-point Likert scale (1-'storngly disagree' to 7-'strongly agree'). The 14 questions cover three constructs: product knowledge, perceived benefits, and perceived risk of a remanufactured gearbox.

3.3 Statistical analysis

The statistical analysis constituted an ordinary least squares estimation (OLS) of the variables. The regression model we used can be presented as:

$$PI_i = \alpha + C_i\beta + X_i\gamma + e_i$$

where PI_i is the purchase intention index of a respondent i, C_i is the vector of perceptions concerning the remanufactured gearbox surveyed in this study, X_i is the vector of the respondent i personal characteristics adopted as control variables, and e_i is the error term.

The elements of each construct are combined by principal component analysis. The composite index of product knowledge is derived from Q1-Q4 in Table A.2. by principal component analysis, and respectively for the remaining two constructs of risk and benefit. Therefore, C_i consists of three composite indices: the index of product knowledge (PK), perceived benefit (PB), and perceived risk (PR).

For the statistical analysis of the survey results, the statistical package for the social sciences (SPSS) software was used, specifically the IBM SPSS Statistics software version 25.

4. Results and Discussion

In this section, the results of the survey will be presented and discussed. The presentation of the results follows the three parts of the survey, starting with the general characteristics and the relative knowledge of the sample population about repairing their car and the option of remanufacture auto parts, continuing with the purchase intention and the analysis of the composite index of perceptions, and finishing with the analysis of the influence of product information and quality certification on consumers' purchase intention.

4.1 Acquaintance and purchase experience of the survey sample

The general characteristics of the sample population are summarised in Table A.1. The sample is well balanced between male and female respondents (50/50), coming roughly equally from all the regions of the country. There is a slightly higher representation of people aged over 40 years old in the sample, while the general self-assessment of repair skills was low with 71.4% of the sample indicating that they don't have any car repair skills at all.

Regarding the respondents' acquaintance and purchase experience of remanufactured auto parts, the results are presented in Table 1. Nearly 6 out of 10 respondents (58.6%) have never heard of the existence of remanufactured auto parts, and an even higher percentage of the sample (76.4%) has never actually bought remanufactured parts for their own use. Moreover, the personal engagement of the respondents with replacing faulty car parts with the equivalent remanufactured parts is remarkably low (14.8%) and can be compared with the experience of Japanese drivers, who rather seldom would engage in such operations (Matsumoto et al., 2017) as it is common in Japan for car parts to be replaced in periodic mandatory inspections, usually before a problem occurs. Similar conditions apply also in Sweden, with Swedish consumers relying on car services provided by OEMs that take care of decisions such as replacing parts.

Table 1. *Respondents' acquaintance and purchase experiences of remanufactured auto parts.*

Item	yes	no
Have you ever heard of remanufactured auto parts?	84 (41.4%)	119 (58.6%)
Have you ever bought remanufactured auto parts?	48 (23.6%)	155 (76.4%)
Have you ever repaired or replaced the gearbox of your car, including that of your current car and/or your previous cars?	30 (14.8%)	173 (85.2%)

4.2 Purchase intention and composite index of perceptions of remanufactured auto parts

The composite index of purchase intention comprises of the three constituent elements ("constructs") of product knowledge, perceived benefits and risks of remanufactured auto parts. The statistical method of combining the constructs into the aggregate purchase intention index aims to seek linear combinations of multiple elements and decomposes them to several principal components that are not correlated with each other. The loadings of the principal components of each construct are presented in Table 2. The elements in each construct have internal consistency provided that the Cronbach α statistic for each set of elements is higher than 0.75. All first principal components are interpreted as overall measures of constructs because the loadings of all constructs are positive coefficients and have similar values. The composite index of each construct is estimated from the loadings in Table 4. For instance, the composite index of product knowledge (PK) is derived as follows:

$$PK = 0.862 \times Q1 + 0.861 \times Q2 + 0.889 \times Q3 + 0.914 \times Q4$$

The values of Q1-Q4 are standardized. The other indices of perceived benefit (PB) and perceived risk (PR) follow the same procedure.

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Table 2. *Composite index by principal component analysis.*

Construct	Element	Principal component	Statistic
Product knowledge	PK1	0.862	
	PK2	0.861	
	PK3	0.889	
	PK4	0.914	
	Eigenvalue		3.111
	Contribution ratio		0.78
	Cronbach α		0.904
Perceived benefits	PB1	0.781	
	PB2	0.886	
	PB3	0.889	
	Eigenvalue		2.185
	Contribution ratio		0.73
	Cronbach α		0.812
Perceived risk	PR1	0.631	
	PR2	0.872	
	PR3	0.721	
	PR4	0.826	
	Eigenvalue		2.361
	Contribution ratio		0.59
	Cronbach α		0.763

Table 3 outlines the regression analysis of the purchase intention (PI) index, following the statistical analysis method presented in section 3.3. The F statistic with 7 and 195 degrees of freedom is 11.303 which means that we reject the null hypothesis that all coefficients excluding the constant are equal to zero. The effects of gender, age, income and self-rated repair skill on PI are statistically insignificant.

Analysing the three constituent elements of the PI index, it becomes apparent that product knowledge (PK) and perceived benefit (PB) affect PI at a statistical level of significance. Consumers with higher product knowledge have a higher purchase intention of remanufactured auto parts, thus H1 is supported. Similarly, consumers that perceived benefits of remanufactured parts would exhibit positive purchase intention, resulting in the support of H2 as well. However, the perceived risk (PR) element, although marginally negative, it does not appear to be statistically significant and therefore it does not influence the PI of Swedish consumers, resulting in the rejection of H3. Such insignificant results of the perceived risk index have not been observed widely in literature, since the majority of existing studies claim that a high perceived risk of remanufactured products constitutes the major cause of consumers' low acceptance of the products (Debo et al., 2005; Guide and Li, 2010; Hazen et al., 2012; Matsumoto et al., 2017; Van Weelden et al., 2016; Wang et al., 2013).

Table 3. *Regression analysis of dependent variable Purchase Intention (PI) index*

Predictor	B coefficient	S.E.	Beta coefficient	Significance level
Gender (Female=1)	0.184	0.117	0.108	
Age	0.007	0.004	0.113	
Income	0.046	0.004	0.099	
Self-rated repair skill (Yes=1)	-0.116	0.161	-0.061	
Product knowledge	0.117	0.022	0.424	***
Perceived benefits	0.116	0.025	0.295	***
Perceived risk	-0.001	0.023	-0.003	
Constant	2.445	0.266		***
Number of observations	203			
F (7, 195)	11.303			
Adjusted R2	0.263			

*** $p < .001$

Only recently, a study by Matsumoto et al. (2018b) in the context of developing and transition (D&T) countries in South East Asia revealed similar results concerning the relevance of perceived risk to the purchase intention of remanufactured auto parts. In that case, the deviance from previous literature evidence was attributed to the fact

that the risk of product inferiority actually exists in those markets and does not constitute a consumer perception. This means that consumers in these countries may reasonably expect the quality of remanufactured auto parts to be lower than new products, and therefore internalise the risk factor in their purchasing decision. In other words, they take for granted that the remanufactured part will not be equal to “like new” quality, a fact which then does not influence negatively their purchase intention – irrespective if the actual quality of the remanufactured part would be “like new” or not.

In the case of Sweden, it is not possible to verify similar consumer behaviour as in the D&T countries. However, a possible explanation would have to do rather with the high level of trust in Swedish society and the expectation of an honest and trustworthy transaction between parties. Research consistently shows a high level of trust in Sweden between individuals and to a lesser degree in institutions and big companies (Martinsson and Andersson, 2019), and therefore it could be argued that this level of trust would expand to transactions between individuals. In the case of car repairs, either at local garages or OEM filial shops, the level of interpersonal transaction is closer to the individual (person-to-person), compared to the dynamics of an international OEM and a single customer. Thus, it is assumed that the customer would trust the repair shop on their claims of product quality and guarantees, even without an official certification to prove it. This means, that the level of perceived risk minimises and the influence in the purchase intention becomes less critical, as shown by the statistical analysis of the results. Although this is just one possible explanation of the insignificant effect or risk perception

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of remanufactured auto parts in Swedish consumers' purchase intention, it would be necessary to further research the causes behind this phenomenon.

Concluding, the mean (M) and standard deviation (SD) of the purchase intention of Swedish consumers, as indicated by the PI index are M = 3.07 and SD = 0.86. These values can be partially compared with previous studies by Matsumoto et al., (2017, 2018a) concerning the purchase intention of US and Japanese consumers. In comparison to these studies, the Swedish consumers exhibit purchasing behaviour similar to Japanese consumers, having lower PI index than the US consumers (M = 4.15 and SD = 1.59) and a comparable PI index with the Japanese consumers (M = 3.19 and SD = 1.56). However, the results between the past and the present studies cannot be compared in absolute terms, since the PI index in this study lacks the additional element of price consciousness (PC). Therefore, the PI index results in lower values, since it is constituted by three instead of four elements. By roughly taking into account the potential effect of price consciousness in the PI index, we expect the purchase intention of Swedish consumers to be similar or relatively higher than that of the Japanese, but still lower than the purchase intention of remanufactured auto parts of the US consumers.

4.3 Quality certification and product information influence

The final part of the survey measured the influence of product quality certification on the purchase intention of remanufactured auto parts of Swedish consumers. Additionally, the survey measured the willingness of consumers to accept remanufactured auto parts in the case this would become a mandatory requirement by direct policy intervention. The results are presented in Table 4.

Table 4. *Response to policy interventions and perception of influence to purchase decision*

	Positive	Neutral	Negative
A quality certification for remanufactured auto parts would affect my purchase decision	148 (72.9%)	36 (17.7%)	19 (9.4%)
I am willing to buy remanufactured auto parts if they are quality certified.	131 (64.5%)	48 (23.7%)	24 (11.8%)
Repairs of vehicles over 5 years old are done exclusively with remanufactured parts.	64 (31.5%)	62 (30.6%)	77 (37.9%)

The results indicate that Swedish consumers are more willing to purchase quality certified remanufactured auto parts than uncertified ones. Despite the results of perceived risk (PR) of remanufactured auto parts, which showed no significance in influencing the purchase intention of Swedish consumers, in the follow-up questions about quality certification, a high percentage of the sample (72.9%) responded that a quality certification for remanufactured parts would positively affect their purchase intention. In this, we identify a credibility booster rather than a credibility determinant, since the level of perceived quality risk was already low. Additionally,

despite the high percentage of positive responds in the need for quality certification, the share of Swedish consumers willing to buy remanufactured auto parts appeared to be lower, 64.5% in contrast to 72.9% of positively inclined consumers to quality certification. By combining the results, we observe that low perceived

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risk of remanufactured auto parts and the provision of information on quality, have moderate influence in the overall acceptance and purchase intention of Swedish consumers. Moreover, the Swedish consumer becomes even more averse to remanufactured auto parts in the case of a mandatory policy intervention for repairing older cars exclusively with remanufactured parts. The results in Table 4 show a slightly negative response and the shares of the sample population being roughly equally divided between neutral and positive reactions. A consumer choice mandate is seen negatively by the Swedish consumers in the case of automotive parts.

Finally, consumers exhibit a higher level of trust in a remanufacturing industry association to develop a quality certification for remanufactured auto parts (Table 5). Further, it seems that they would trust more an OEM (car manufacturer) than a governmental or public organisation. These answers reveal the high trust of consumers to the domestic automotive industry to set standards of quality for remanufacturing. Thus, the industry, having a widely accepted and positive brand reputation, it can reduce perceived risks and act as an guarantor of product quality (Hamzaoui-Essoussi and Linton, 2014). Similarly, a positive seller reputation and approval by the OEMs increase the consumers' willingness to pay for remanufactured products (Pang et al., 2015). This may create opportunities for both OEMs and remanufacturing industrial associations to develop appropriate certification schemes and provide certified remanufactured auto parts in their markets, thus increasing consumers' acceptance.

Table 5. *Most trusted organisation as certifier of remanufactures auto parts.*

	N (%)
Government or Public organisation	39 (19.5)
Remanufacturing industrial association	63 (31.0)
Car manufacturing company	47 (23.0)
Remanufacturing company	23 (11.2)
International standard organization	31 (15.3)

5. Conclusion and recommendations

The consumption of material resources is increasing globally, despite efforts to increase resource efficiency in industry, especially in emerging economies. In Europe, the EU has adopted several strategic plans towards the direction of reducing resources consumption, aiming at higher resource security and economic sustainability of its manufacturing industries. Diffusion of remanufacturing is important for mitigating the increased resource consumption and for easing the pressures on the natural environment. However, to scale up remanufacturing operations, it is necessary for consumers to accept remanufactured products.

This article presented the results of a survey of Swedish consumers, analysing their knowledge of remanufactured auto parts and their perception on associated benefits and risks, which are factors contributing to their overall purchase intention. The results revealed that Swedish consumers have limited knowledge about remanufactured auto parts. Nevertheless, they do recognise the benefits of using remanufactured auto parts without showing a significant risk aversion in their purchase decision, being less preoccupied by the risks entailed in buying a remanufactured product. This last result comes into conflict with much of the existing literature which claims that consumers' perceived risks of remanufactured products constitute the major cause

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of the lack of diffusion of remanufacturing (Debo et al., 2005; Guide and Li, 2010; Hazen et al., 2012; Matsumoto et al., 2017; Van Weelden et al., 2016; Wang et al., 2013). Therefore, further studies on this topic are needed to identify the underlying reasons for this behaviour of the Swedish consumer. In the current study, the sample of the survey consisted of 203 individuals, which might have posed a limitation in the representativeness of the results. A larger sample, therefore, might be needed to extract statistically safer conclusions.

Based on the previous literature which identified lack of information and perceived risks as major barriers for the upscale of remanufacturing operations, the survey was designed to include also consumers' opinion on potential measures to bridge the identified gap in knowledge, by providing information and quality certification of remanufactured auto parts. The results showed that although the Swedish consumers trust a quality certification scheme for remanufactured auto parts – preferably set up by an industry association – that would not be the most critical factor in their purchase decision. High trust in the information of the certification label did not translate into equally high purchase intention of certified remanufactured auto parts in the survey results.

Therefore, it becomes obvious that the introduction of quality certification for remanufactured auto parts has the potential to be a useful policy instrument to increase the uptake of remanufactured products, but it is not sufficient. Making information available does not necessarily lead to more sustainable consumer choices (Leire and Thidell 2005; Mont and Power 2010; Ölander and Thøgersen 2014). To increase the effectiveness of informative policy instruments, such as quality certifications, the combination of the certification with other policy instruments, for instance public procurement, has been recommended (Gåvertsson et al., 2018). Public or private (business) procurement has the potential to influence the demand of remanufactured auto parts and send a clear signal in the market, by setting specific requirements on market actors. A comprehensive policy mix that could influence the upscale of remanufacturing operations would include: a) a constant quota of available remanufactured auto parts vs. new parts in the stock of spare parts of OEMs (as for instance 15% in the case of Volvo Cars) with a gradual increase, thus incentivising not only remanufacturing operations but also the effective collection of cores; b) a quality certification scheme of remanufactured auto parts, ideally by a remanufacturing industry association; c) clear criteria in procurement administrative processes that prioritise the use of remanufactured auto parts, which coupled with the lower pricing of remanufactured products, it would become the obvious choice for any procuring authority; and d) an optional eco-label documenting the environmental benefits of each remanufactured auto part.

Although this article measures the factors influencing the purchase intention of individuals, it is inexorably connected with action at administrative or business level as well. Municipalities or business entities can be expected not to have negative preconceptions towards quality or reliability of remanufactured products as private individuals may have. However, a recent study by Wasserbaur and Milios (2019) in Swedish municipalities revealed that it is not uncommon that selection bias and user preferences of the procurement officers occur during the drafting of tender specifications, as procurers are more likely to prioritise/prescribe the utility or the product they are familiar with. This is also reflected in research by Sporrong and Bröchner (2009) suggesting that procurement officers hold individual preferences, which are mirrored in their procedures for procurement. Therefore, the study of individuals' perceptions of remanufactured products is of the highest importance, and further studies would be beneficial for understanding consumers' attitudes and influencing consumer's acceptance towards remanufactured products.

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Appendix

Table A.1. *Descriptive statistics for socio-demographic variables*

Variable	N (%)
Gender	Male: 101 (49.8)
	Female: 102 (50.2)
Age M = 50.20, SD = 14.60	
Age 20-29	22(10.8)
Age 30-39	30 (14.8)
Age 40-49	41 (20.2)
Age 50-59	48 (23.6)
Age 60-69	43 (21.2)
Age 10-74	19 (9.4)
Income	
Under 100,000 SEK	7 (3.4)
100,000 SEK – 249,999 SEK	17 (8.4)
250,000 SEK – 349,999 SEK	30 (14.8)
350,000 SEK – 449,999 SEK	22 (10.8)
450,000 SEK – 599,999 SEK	36 (17.7)
600,000 SEK – 749,999 SEK	45 (22.2)
750,000 SEK – 999,999 SEK	37 (18.2)
Over 1,000,000 SEK	9 (4.4)
Self-rated repair skill	Yes: 58 (28.6)
	No: 145 (71.4)
Place of residence	
Capital region (Stockholm)	29 (14.4)
East Sweden	30 (14.8)
South Sweden	52 (25.6)
West Sweden	48 (23.6)
North Sweden	44 (21.6)

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Table A.2. *Questions for measuring perceptions.*

Construct	Element (seven-point Likert scale)
Product knowledge	PK1: I am familiar with the performance and features of a remanufactured gearbox compared to that of new.
	PK2: I am familiar with quality of remanufactured compared to that of new.
	PK3: I am familiar with the differences between a remanufactured and a re-used gearbox.
	PK4: I am familiar with the price level of remanufactured compared to that of a new gearbox
Perceived benefit	PB1: Purchasing remanufactured instead of new can result in lower purchasing costs.
	PB2: Purchasing remanufactured instead of new can lead to resource and energy savings.
	PB3: Purchasing remanufactured instead of new can reduce the adverse effects on the environment.
Perceived risk	PR1: The quality and the safety of remanufactured is not as good as that of new products, so remanufactured may pose a higher safety risk (physical risk).
	PR2: Remanufactured gearbox does not perform and function as well as a new product, so remanufactured may pose a higher performance risk (performance risk).
	PR3: Purchasing remanufactured may not be a good investment (financial risk).
	PR4: I may have to return to the garage for repairs more frequently if I use remanufactured (time risk).

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Helping people to help themselves? Care and repair in DIY initiatives

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Abstract

Over the last decade policymakers, funders and academics increasingly are interested in discussing the potentials of DIY initiatives to contribute towards sustainability transformations. A growing number of people fix and make their own products through small-scale, decentralized workshops (e.g. Repair Cafés and Makerspaces). Initiatives are said to promote citizen empowerment and collaborative practices and therefore strengthening social transformation processes. Some of the initiatives' narratives connect readily to policy agendas for neighborhood regeneration and inclusive innovation. Other narratives derive from civic activism, expressing that initiatives 'help people to help themselves' to develop a countermovement against the increasing throwaway society. As yet, there is little social scientific research that looks closely at the processes of repairing and making things together and how the narratives manifest on the ground: whether the empowerment of citizens through DIY activities enable more sustainable consumption patterns. The proposed paper draws on recent conceptual work on 'care' and 'repair' that considers caring both to be a practical and ethical matter taking into account human-object relations and human-human-interactions through objects. The notions of 'care' draws attention to moments of learning and politics where a range of normative and emotional activities are enacted through collaborative repair and making that can be empowering but also are inherently fragile and vulnerable. Citizen science research has been conducted to investigate processes of 'helping people to help themselves'. A set of so called 'cultural probes', a creative method coming from design research to explore people's daily lives, has been drawn upon and adapted for citizen science. Our cultural probes comprised of fifteen activities co-developed with and sent to the citizen scientists who engaged with the probes by taking photos, drawing pictures and telling stories whilst collecting data through self-observations. The data collected through 'cultural probes' was analyzed together in participatory workshops and in-depth interviews. Preliminary results show that narratives of 'helping people to help themselves' are perceived, interpreted and experienced very differently in DIY initiatives. The coming together of humans and objects to provide 'care' and in turn depend on 'care' i.e. fixing things together is not always straightforward. Repairing things together is often linked to a strong sense of caring for one's objects. Nevertheless, this is not the complete story. For most of the citizen scientists, the experience of engaging in repairing and making cognitively, physically and sensually as well as doing things together, are manifold from fear of failing to 'care' for the human and object to delight of sustaining and remaking ties between human and object. These experiences play a key role whether repair work is started (or not) and can be seen as an important driver to appropriate the relevant know-how and invest time to be able to further engage in these practices together. The proposed paper will elaborate our empirical findings and relate them to a broader debate on social transformation towards sustainable consumption.

Keywords: Caring, Repair Cafés, Collaborative Repair, Citizen Science

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1. Introduction

In recent years, academic interest in the subject of repair has been growing (Houston et al. 2016, Rosner and Ames 2014, Jackson 2014, Maestri and Wakkary 2011). Engaging people in repair is considered to be a step towards sustainable consumption through prolonging the lifetime of objects (Charter & Keiller 2014). Moreover, existing work has looked at repair within collaborative DIY initiatives, including people's understanding of repair and making as new social movements (Kannengießer 2017, Kuni 2016, Grewe 2015, Rosner 2013). So far, there are only a few investigations that deal with building an understanding of people's practices of repair, social relations and engagements with objects in the collaborative repairing spaces. Particularly rare are investigations that deal with the practices of repair and notion of care in the context of DIY initiatives (Jaeger-Erben et al. 2019).

The proposed paper tries to fill this gap through answering the following research questions: 1. What role does the notion of 'care' play in doing repair activities in Repair Cafés? 2. What dimensions of care come to light when examining repairing together in Repair Cafes? The questions were tackled by a mixed-method approach based on citizen science research. We draw on critical feminist understanding of the notion of care (Tronto 1993, Winker 2015) and its application in science and technology research to develop an understanding of 'care' work in Repair Cafés. Following the understanding from Tronto (1993:104 and 161), caring is understood as "not simply a cerebral concern, or a character trait, but the concern of living, active human engaged in the process of everyday living" and as "a quality necessary for democratic citizens to live together well in a pluralistic society, and that only in a just, pluralistic society can care flourish". Moreover, we draw on the work of Denis and Pontille (2015) and Mol et al. (2010) about taking care of objects, in which the notion of caring has been broadened to the material environment and the fragility of material objects. This paper examines the notion of care within repair activities in Repair Cafés, which refer to several people and objects relations. The paper is structured as follows: first, the current repair and linked sustainability debates are reviewed, followed by a discussion of the 'care' approach in feminist theory. Second, the methodology and research process is outlined. Third, the preliminary research results are presented and discussed. Finally, we end with some conclusions.

1.1 Background: Repair and sustainable consumption

Current production and consumption patterns in industrialized countries are associated with high social and environmental costs; for example, they are not sustainable in terms of their resource use and waste rates (Baldé et al., 2015, 2017). Longer life and longevity of consumer goods are seen as a key factors in increasing resource efficiency and encouraging sustainable consumer patterns, especially in the field of electronic equipment (UNEP, 2011, Reuter and van Schaik, 2008). Thus, a change in production and consumption practices and the associated prolongation of the use and lifetime of consumer goods is represented as a meaningful approach (Winzer 2015, Prakash and Dehoust, 2015). Currently, two opposing developments on the consumer side can be observed in this context. On the one hand, despite technical advances, the lifespan of some devices is decreasing (Wang et al., 2013), they are being prematurely replaced, although, they are still usable, they are not being repaired or upgraded, instead new devices are being purchased. Some of them seem to better perform the desired functions (Jaeger- Erben et al., 2016, Wieser et al., 2015). On the other hand, in recent years, more alternative practices have emerged from society to strengthen a 'culture of repair' (Heckl, 2013, Blau et al., 1997). Repair and/ or do-it-yourself movements (Anderson 2012, Ratto and Boler, 2014) come up with practical solutions in this problem constellation. The idea is that people re-acquire use and repair skills when dealing with their consumer goods, knowing how they are built and functioning, and what they need to do to repair and/ or change them in order to use their devices for as long as their appropriate lifetime (Charter and Keiller, 2014). As a symptom of this movement, a variety of repair initiatives and so-called Repair Cafes have emerged in recent years (ibid.). It is not just about the practical repair of a broken object in Repair Cafés but also as a complex social phenomenon that can transform the order and meaning of socio-technical systems. Moment when objects are being 'opened up' as part of the repair process, allow people to make novel encounters with them (i.e. they get to know the 'inner' life of their objects). Seeing whether objects can be easily repaired or not can also lead to people questioning the design and production process of existing consumer goods (Jackson, 2014).

Further, repair can be conceptualized as a creative and improvisational process in which people can develop novel relations with objects e.g. the creative reuse of products (Maestri and Wakkary, 2011, Kuni, 2016). In order to be able to participate in the process, people need access to tools, technologies, skills and knowledge that enables them to repair objects. Particular material arrangements and processes of knowledge transfer play a very important role in repair. Some of these processes have been simplified by the development of web-based information and knowledge platforms about how to do repair (e.g. You tube videos of repairing object, products and repair descriptions on various websites). In addition, digital networking is leading to a greater and faster exchange of knowledge among practitioners (e.g. digital exchange between DIY initiatives, disseminating information about networking meetings). Some advocates and researchers have therefore spoken about a repair movement, promoting and living a 'culture of repair' (Kuni, 2016, Rosner, 2013, Bertling and Leggewie, 2016, Kannengießer, 2017).

The 'culture of repair' calls for alternative practices and ways of thinking about the use and consumption of resources. It is often interpreted as a counterbalance to 'planned obsolescence' (Kuni, 2016, Bertling and Leggewie, 2016). In addition, repair practices and developments in the repair movement provide a new impetus for sustainable economic models (Longhurst et al. 2017), as well as, for a study of human-object relationships and their role in the emergence of new forms of consumption (Dewbarry, et al., 2016). In academic discussions on repair, it is often considered to be a moment of taking responsibility or developing an awareness of one's own/ shared responsibility. New practices of collaboration and bourgeois self-empowerment are regularly framed as civil society reform strategies, which connects the grassroots initiatives and sustainable politics (Jackson, 2014, Bertling and Leggewie, 2016). However, often these collaborations, empowerments and strategies are taken for

granted rather than being critically interrogated. There often is a lack of systematic consideration of vulnerabilities, inequalities and injustices within exisitng theoretical and empirical work on DIY initiatives. Issues of privilege related to repair practices is frequently only discussed in the context of repair in the Global South, for instance, associated with the availability of information, knowledge, spare parts and tools (Houston et al., 2016, Rosner and Ames, 2014). This research has made use of the notion of care to critically examine practices and relations connected privileges associated with repair.

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1.2 Conceptual framing: Notion of care

For several years, conceptual developments around the notion of 'care' has become the subject for various academic disciplines such as social philosophy, sociology, political science, nursing sciences and economics (Aulenbacher and Dammayr, 2014). The concept of care enables the thematisation of broad aspects of social life, from caring, concerning mindfulness through activities of caring, provide for, to caring for oneself and others (see Brückner, 2010, Conradi, 2001, Gubitzer and Mader, 2011, Nickel, 2008). Care is also described as an 'element of ideal social practices' and 'being in relationship as a hallmark of human existence' and as a 'comprehensive perspective of connectedness' (Kohlen and Kumbruck, 2008:2-4) and care work as 'life-sustaining, essentials activities without which societies would not be viable' (Madörin, 2006:283).

In addition to such aspect of the notion of care, an economic conceptualisation plays an important role, along with feminist criticism of the juxtaposition and intertwining of paid and unpaid work, including associated work and production relationships (Haidinger and Knittler, 2016). In questioning the logics of capitalism, not only human resources are addressed in terms of exploitation and annihilation, but also the natural resources: 'the capitalist system [is] about to destroy the resources on which it builds, namely humans and nature' (Winker, 2015:147). In order to counteract these destructive processes, a social alternative in the form of a 'care revolution' is needed that pursues the goal of building a solidary society. The 'care revolution' as a transformation of society, which is supposed to lead to a new form of solidarity living together through the learning of practices of togetherness and action in solidarity (ibid.).

This idea has similarities with the concept of the 'great transformation' (WGBU, 2011), which is also a process of change at all levels of society. These transformation(s) also affect the everyday life and living environments of people and are also carried into consumption practices in particular. The potentials of transformation are anchored in the way of life and thus in everyday practices (Brand and Wissen, 2017). By questioning one's own way of life and associated privileges, a capitalist logic can be transformed into a sort of care logic (ibid.). At this point, the argument goes back to Tronto, who sees care as a tool for critical political analysis, as well as, a basis for political (social) change and a strategy for society's organization (1993:172-175).

More recently, Mol et al. (2010) have argued that care and technology have been considered to be opposites throughout the whole twentieth century. With its affiliation with the private sphere, care has been considered to be emotional, unpredictable, and a kind of calling. Whereas technology was termed cold, rational, and effective. This binary thinking has long prevented bringing these two areas of conceptualization together (Mol et al. 2010). This has started to change with the second women's movement and the increasing influence of female scientist in the academic world.

Based on our empirical data, we show that repair is not only grounded in the "care of things" (Mol et al., 2010), but also includes a variety of other aspects of care work, which has currently received very little consideration in academic discussions. The inclusion of the concept of care in the investigation of repair can make novel aspects visible. Further, it can potentially contribute to overcoming the binary between care and technology.

2. Methods

There is little research that draws on the notion of care to interrogate human/ object relations and their importance for doing repair in DIY-initiatives. In this section, we outline how these relations and processes have been investigated. It describes our methodological approach: citizen science research.

2.1 Citizen science research

Current social science methods seem to be of limited use to study everyday repair activities. This is why this research is grounded in citizen science research. Citizen science research is based on the public participation and collaboration in science research (Rückert-John et al. 2017). Frequently, citizen science has been conducted through collective data collection activities rather than co-designing project aims, methods and analysis. This research aimed to make use of methods for collaborative data collection and analysis between academic researchers and citizen researchers, who can be seen as a part of the repair and DIY movement. An open call for participating in the research was distributed through several mailing lists of repair and DIY networks. Additionally, project partners from the repair and DIY movement spoke to organizers, visitors and members of several repair and DIY initiatives to gather possible participants in the research. In total, thirty-two citizen scientists took part in the research at four Repair Cafés and Makerspaces across Germany between March 2018 and December 2019. The sample was diverse in age, socio-economic background, roles taken in the initiatives (e.g. visitors, members, and organizers), and repair and DIY skills and knowledge. The citizen science research was grounded in a mixed-method approach that made use of 1) cultural probes (method derived from design research), 2) two participatory research workshops in four locations, and 3) sixteen follow-up in-depth interviews. These methods are described in the following sub-sections.

2.2 Cultural Probes

Cultural probes are packages of open-ended, creative activities that participants in the research (and in our citizen science research) engage with on their own terms and in their own time, including creative tasks such as maps to complete or cards to fill in, as well as, cameras, photo albums and postcards (Gaver et al. 2004). These designed probe tasks reflect an articulation of the probe designer's thoughts that are then send to the participants/ researchers. The participants/ researchers have to interpret these forms of expression in their own time at home and by undertaking the tasks they express theirs. These interpretations and reflections are finally revealed in the returned probe packs often challenging the probe designer's own perceptions. To emphasize this challenge, Joensson (2004:24) draws attention to the 'friction' included in the probes that potentially can encourage participants and researchers to view environments, situations and objects in a new light 'with new glasses'

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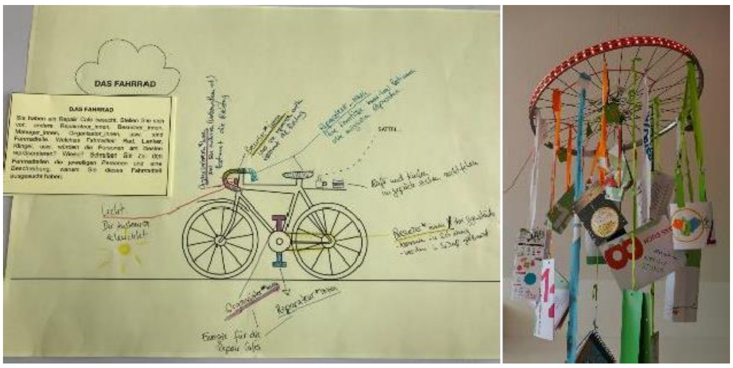
Cultural probes have opened up new ways of thinking about design-led research methods that can work alongside, or contest, more reductive science based approaches to research. Sociologists have adapted and reinterpreted cultural probes for a variety of settings and design/ research projects to understand people's lives, values and aspirations (Joensson 2004). However, there are clear distinctions between Gaver et al.'s work and these adaptations. For instance, Graham et al. (2005) have highlight the potential of gaining informational data by combining probes with interviews and criticized the 'lack of formal analysis' in the probe technique (Mattelmaeki et al. 2002). The more instrumental use of the probe method in the adapted approaches has led to Gaver et al. (1999, 2004) emphasizing the uncertain, ambiguous, and subjective nature of probes, criticizing this 'tendency to rationalize' the method (2004:53). Fundamentally, Gaver et al.'s (2004:53) approach to probes emphasizes 'the notion that knowledge has limits'. The returned probes provide 'fragmentary clues' about the participant's lives, experiences and routines.

In this research, we created probe packs with 15 tasks (in collaboration with the project partners and citizen scientists) that were sent to the citizen scientists. The packs have included a mixture of informational and 'inspirational' i.e. fragmented clues data gathering activities. Our aim was to appropriate the method for citizen science research to encourage the citizen scientists to engage in and record self-observations and reflections about their repair and making practices. For instance, informational data was gathered through citizen scientists keeping a repair diary, whereas inspirational data was collected through them writing an obituary for one of their objects and representing the social structure of a Repair Café in relation bike parts (e.g. who takes the role of the handlebar?). Our cultural probes comprised of activities such as taking photos, drawing pictures and maps, or inventing and telling stories. The citizen scientists had about three months to engage with the tasks before coming together for the participatory research workshop.



2.3 Participatory research workshops and follow up in-depth interviews

Two participatory research workshops were conducted in four locations (in total eight workshops). The first workshop was conducted prior to sending out the probe packs. The aim was to trial and co-develop the probe tasks in the pack with the citizen scientists. The second workshop took part after the data-gathering phase i.e.

engaging with probes at home. Here, the data collected by the citizens was collectively analyzed as part of 'thematic analysis' groups based on individual probe comparisons. At the end of the workshop, each group made up of citizen and academic scientists shared their findings and conclusions.

Furthermore, in-depth face-to-face-interviews were conducted with sixteen citizen scientists, who wanted to continue with the analysis of their probe pack. The interviews allowed academic researchers and citizen researcher to delve more deeply into people's own probe pack and deepen the citizen's individual 'repair biography'.

The qualitative data collected has been analyzed drawing on grounded theory (Böhm 2007, Strauss and Corbin 1996). This methodology offers a sequence of procedures for the development of an inductively guided theory of a social situation. The procedure leads to the creation of an object-related theory that serves the description and explanation of the examined social phenomena. First, we used open coding to analyse the data. A series of codes emerged whose analysis yielded four dimensions of care: 1) taking care of the objects 2) taking care of each other 3) taking care of the community 4) taking care of the environment.

3. Results and discussion

Our analysis has identified four dimensions in relation to care in repair: 1. taking care of the object, 2. taking care of each other, 3. taking care of the community, and 4. taking care of the environment. These four dimensions' overlap when doing care and repair in Repair Cafés. These therefore are empirical descriptive boundaries that help us to show the specifics of and the differences between each dimension as well as emphasize what happens between each adjacent dimensions (see Figure 1). As shown in the figure below, the four dimensions of care form a circle, which shows that the transition between evolved dimensions is fluid. Between each two adjacent dimensions of care additional processes take place, which in turn can lead to changes in different areas of life i.e. buying new objects or prolonged use of clothing. The interaction and respectively relation between the dimensions "object" and "each other" may lead to changes in the human-object relationship as well as in the human-human relationship. Similarly, the interrelation between the dimensions "object" and "community" can potentially lead to an increase of the social interactions and engagement in the neighborhood, between the dimensions "community" and "environment" to a spreading of sustainable ways of life beyond the neighborhood, and between the dimensions "environment" and "object" to an increase of saved resources.

In addition, we could identify a few significant features in process of repairing that relate to notions of care:

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search for help, knowledge transfer, competence acquisition, and experience of self-efficacy. The features are important because there are present in all care dimensions and influence repair activities.

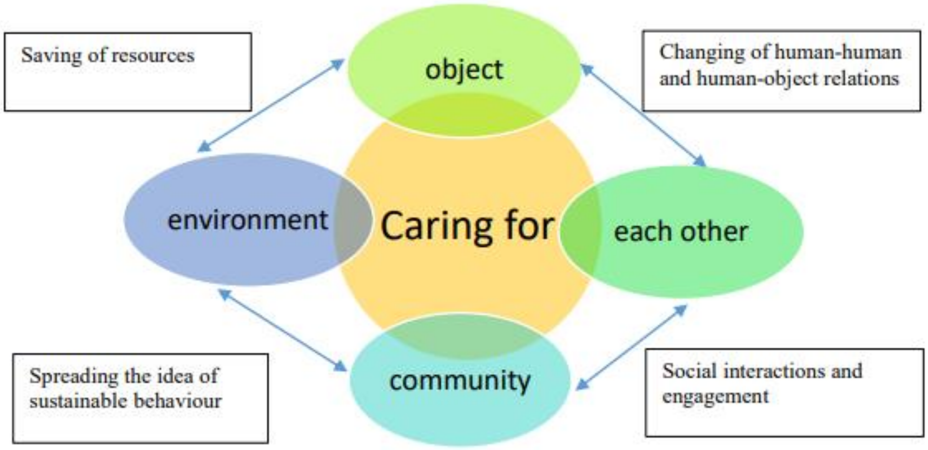

Figure 1: Dimensions of care

The following section is divided into two sub-sections. First, the dimensions of care are presented and how they play out in Repair Cafés. Second, the dimensions of care are analyzed in relation to the identified key features that make up care in repair to be able to answer our research questions.

3.1 Description of care-dimensions

Caring for objects

Caring for objects is understood as the relationship between people and objects, which causes people to think about/ look after their objects. On the one hand, a smooth running of everyday routines depends on functioning objects; on the other hand, the functionality of the device often depends on caring activities of their owners, such as maintaining and cleaning activities.

Before visiting a Repair Café, the owner needs to decide if an object is in need of repair and should be looked at in a Repair Café. This decision is frequently based on a subjective value of the object. The person's emotional attachments to an object play an important role in this process.

„And now, I'm working in a social enterprise. And they have a textile and design workshop and I can leave my jeans to be repaired…. you want to somehow still keep what you love and do everything to keep it alive, so to speak. The jeans are the clearest example of a thing that I want to keep alive" (Domenico).

"The espresso machine that I love…." (Lisa).

Often people 'love' objects that have stories attached to them about loved ones. These objects are reminders of good times and feelings that help to cope with a hectic life. These objects provide stability, security and emotional welfare to the owner. It might be possible to suggest that people look after these objects but that these objects also care for us.

"Alzheimer sounds so funny, but it's not diagnosed, but… I forget pretty much anything that is important. And that's why I've just noticed when I moved house that I need such anchors [i.e. objects]. Or that I keep many items. I call them anchors. Actually, they are meaningless, dust-catching glass ball, but I am attached to their stories. And I just should give this ball away now. I suspect, I should also lose this story, so to speak" (Domenico).

Taking care of an object sometimes means 'admitting defeat' i.e. acknowledging that one has not enough knowledge and/ or skills to repair the object and that help needs to be gained from someone else. This sometimes is not an easy moment. In Martina´s case, the laptop is also a tool that she needs for work, so it must be repaired as soon as possible, which makes the decision to search for help a little more urgent.

„As I said, with this laptop story, first, I dared to try to fix it myself. And then, I went to a Repair Cafe because I thought okay… soldering is not me, then, I'll see if they can help me" (Martina).

For some of the citizen scientists, acts of repair are closely connected to issues of sustainability. The motivations for keeping an object or keeping it alive is part of deliberate sustainable consumption patterns.

"The second is more of an environmental aspect, that I think that the moment I manage to fix something, it naturally lasts longer and requires less production and less need to be thrown away. So in the sense of: The best waste is the one that does not accumulate" (Emil).

In addition to environmental aspect and keeping up daily routines with objects, the emotional attachment to an object seems to be the most common motivation for repair. A personal attachment to an object seems to be the trigger of the whole repair process. Moreover, another value of repair is that objects can create safety factor, the object gives its owner a kind of stability and comfort. Those form the starting point and the condition for the search for help.

Caring for each other

Caring for each other is understood as the differing social interactions in Repair Cafes before, during and immediately after the repair. In contrast to repair as a paid service, repair in the Repair Café always requires a deeper exchange between the repair participants.

It often is only through the joint care for an object that the 'expert' repairer and owner of the object establish a mutual exchange in a Repair Café. The object becomes a medium, which can enable a human-object-human relationship.

"If the visitor is interested, 'expert' repairers are ready to explain what they are doing… and I think that alone creates a certain familiarity with the object even for the visitor. As with the activity itself... this disassembly

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and that… a laptop… may… not die immediately… then you release a screw or something… just a little demonstration… of courage... How can a nerd biotope help with self-help… - by taking people fear of contact [with the object]" (Domenico).

Taking care of each other is considered to be highly relevant for the atmosphere in a Repair Café. These spaces are framed to be collaborative spaces in which people aim to create a pleasant and friendly environment. People aim to show respect to one another and take them for whom they are. Mutual appreciation and recognition are considered to be key values in Repair Cafes, which are also grounded in the fact that these spaces, mostly are kept alive through volunteer work.

"So, I thought, the last time I was there [Repair Café], so the mood is always kind of good, they are nice people, they tick similar... of course there is always one, who is repairing, who is a bit awkward or something like that, but good, that's just human, but it's okay, too. Because maybe his strength is just not to be happy… but to be facing… the device and I'm doing it now, that's my goal. Everyone according to their own strengths and that's the nice thing, I think. You meet new people, there is always somebody else" (Jana).

Caring for each other is not always a straightforward matter. Even, if there is the desire to create a friendly atmosphere and a safe space, it is not always possible to convey these desires to the Repair Café visitors. They often feel overwhelmed. Informal rules of a Repair Café are not always visible straight away (for instance, how do people take turns to see the 'expert' repairers). Moreover, visitors can be uncertain about their own repair skills and knowledge. This uncertainty can sometimes lead to a fear of failure and non-fulfillment of expectations (e.g. that the object will definitely fully function again). The decision to visit a Repair Café despite these potential negative feelings and seek help is often a difficult one, weighing up between the hoped-for results of the repair and exposing oneself to potential vulnerabilities (e.g. not having adequately looked after the object or not beings able to open it up).

"In this Repair Café if you're an active [visitor], you should just have a go, and they will guide you. But if you feel like that you really have no idea and are scared to touch the object, the 'expert' repairers struggle to know how to integrate you. This is how visitors are usually treated at the moment. The question is if visitors are really integrate into the repair process… or are seen as annoying. I think the harder the task is, the more you have to overcome it, to think, all right, then I'll just put myself in this unpleasant situation to solve this problem. The problem solving point is more important to me than this inconvenience" (Martina).

Some visitors feel left alone and seem to be confronted with too many expectations of their own when visiting and repairing objects in a Repair Café. This feeling possibly results from the issue that many 'expert' repairers in Repair Café have to learn about how to convey knowledge and skills about repair i.e. the social competences to encourage visitors to learn and explore. Repair Café organizers often express the goal to achieve a knowledge transfer between the 'expert' repairer and visitors to learn about the objects themselves (e.g. how to look after them) and the ability to repair them (rather than throwing them away whilst potentially still functioning). In order to achieve this goal, visitors should come into 'contact with' the object and thus reduce the fear of opening them up and potentially damaging it, and maybe even repair it on their own one day.

"Well, I also want them [visitors] to learn something that's the way the Repair Cafe is… the way it is meant to be. People should be involved. Even if they just learn how to better us and look after the object and to handle tools. Or they might change how they think about things, encouraging the idea that things can be repaired" (Domenico).

At the moment, caring for each other seems to be a difficult affair for both sides. The repairer and visitor can be uncertain about their own role and meeting the expectations of their counterparts. Repairers need to find ways to make the visitors feel neither left alone nor overwhelmed. Such interactions require social competences on both sides that cannot always be met. The ambiguity involved in these interactions can sometimes prevent the knowledge transfer and competence acquisition.

Caring for community

Caring for community is understood as community development activities in the neighborhoods where the Repair Cafes are located. This is seen as countering an increasing sense of social alienation.

For many of the people, who volunteer at a Repair Café, these spaces also play an important role in their local neighborhood development, allowing people to be involved in civil society activities. Attending to perceived unaddressed social and environmental local issues, is for many of the volunteers an important factor to commit time and energy in their local Repair Cafes. Spaces like Repair Cafes are seen to be adding value to the local area and improving the quality of the neighborhood.

"It [Repair Café] simply raises the quality of the neighborhood. The neighborhood does not just go downhill and does not' get out of hand'... And people know, there's a Repair Café. I think it is a kind of anchor to somehow create or maintain the quality of life in the neighborhood or contribute to the quality of a neighborhood" (Domenico).

Even for the visitors are Repair Cafés important places of communality, although, for many of them the way to the Repair Café is a long one. Repair Cafés contribute to the re-emergence of infrastructure that encourage social coexistence. Suddenly, people have a physical space again where they can get together and engage with each other. Especially for people, who have lost a lot of their social connections and therefore live in isolation, these spaces can be a way to re-participate in social life, be involved and feel that they belong.

"The other is, of course, that you have community again, that people get back together, that they sit together again, that they do something together, that maybe someone, who has been alone for a long time… is involved in the community again and can participate in the local social life, and it is also beneficial for him. To get just the appreciation, that's very difficult today, even with many older people" (Jana).

For both groups, the repairer and visitor, Repair Cafes play an important role to have a sense of belonging to a

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community. In addition to being able to (re) integrate and participate in social life, the aspect of experiencing self- efficacy sometimes is important for the participants. Through participating in Repair Café activities people gain a kind of "power of influence" in the neighborhood and thus social design power of everyday life.

Caring for environment

Caring for the environment is understood as an important factor in deciding to visit or volunteer in a Repair Café. The main point is to emphasize sustainability issues such as conserving resources or extending the lifetime of objects.

Participating in a Repair Cafes does not just mean, taking care of the local neighborhood or an object. Engagements in local spaces often has also other reasons, it can be an expression of people's protest against existing environmentally damaging activities and finding alternative, more sustainable practices in their daily life.

Further, it is a form of resisting the perceived disposable/ throw-away mentality. The goal is to save resources by repairing people's existing objects sot that they can use them as long as their appropriate lifetime.

"Expert repairers show their appreciation to the visitors and their objects… In any case the environmental issues [associated with the object] and the throwaway society is thereby a bit diminished and… other opportunities are shown that it is possible [to repair objects]…. The most environmentally friendly item is the one you already have. Of course, you can replace an old fridge, only the new refrigerator will cost resources again" (Domenico).

Caring for the environment and saving of resources is a key issue for a lot of visitors and 'expert' repairers. It seems that participating in a Repair Café is part of larger concerns about global environmental problems. For them, a key question to be answered is how to increase people's awareness about these issues in society.

„… that you have respect for the objects... Or even how to use resources that's what I think is a bit of a pity that resources are wasted… because they are finite. They are not infinite and we are already aware of the global development consequences. To create further bottom up awareness that is very difficult that would have to happen top down" (Jana).

For many people involved in Repair Cafes, environmental protection and conservation are the motivations behind doing repair in everyday life. For the group of repairer, knowledge transfer plays an elementary role. For the group of visitor, the acquisition of competences surrounding repair is important, which can be used at a later date, thus repairing objects rather than buying new ones. Both groups expect positive effects of their own actions on the environment.

3.1 Discussion

This section analyzes the dimensions of care in relation to the identified key features (e.g. search for help, knowledge transfer, competence acquisition, and experience of self-efficacy) that make up care in repair to be

able to answer our key research question: What role does the notion of 'care' play in doing repair activities in Repair Cafés? What dimensions of care come to light when examining repairing together in Repair Cafes?
The empirical descriptions of the four dimensions of caring has shown different aspects of the process of repairing objects in Repair Cafés. Especially, for the dimensions of caring for object and caring for each other, moments of seeking help as a visitor plays an important role. With the dimensions caring for each other and caring for environment, the aspect of knowledge transfer became clear. Competence acquisition came to the fore at the dimension caring for each other. The specific thing about the fourth significant moment - experience of self- efficacy - is that it can be found in all four dimensions in different intensities.
The results have also shown that caring does not end with the objects. Rather, taking care of objects is just one of the many aspects of caring in repair situations that take place outside of one's closest home. This finding strengthens Mol et al.'s (2010) argument that the separation between care and technology is an artificially one (derived from examining the gender-specific division of labour and role models). It therefore is important to extend the concept of care to other areas of everyday life (besides taking care of other people as a family matter or a form of professional employment) as we can show with the repair examples.

4. Conclusions

This article presents novel insights from citizen scientific research making use of the notion of care to examine repair activities in Repair Cafes. Taking up our research questions: What role does the notion of 'care' play in doing repair activities in Repair Cafés? What dimensions of care come to light when examining repairing together in Repair Cafes? Our preliminary results can be summarized as follows.

We have identified several dimensions of care (before and during a visit to a Repair Café): 1. Taking care of the object, 2. Taking care of each other, 3. Taking care of the community, and 4. Taking care of the environment. Each of the four dimensions plays a variable role in the process of repairing and affecting it. They influence the decision for or against repairing an object, the willingness to accept certain way of dealing with one another or not, and also the decision for or against a voluntary commitment in a Repair Cafe.

Our results have shown that people's care for objects are of importance so that it comes to repairing them in Repair Cafés. Whether or not the owner of a broken object is concerned about a possible repair depends largely on his/
her emotional attachment to the object. Moreover, the necessity of an object to keep up with normal routines in everyday life also decide whether to look for repair help, if a repair is not possible at home.
Examing the repair process has shown how issues of vulnerability make up the activities of repairing objects together in Repair Café, which arise through people reflecting on their own role and repair abilities. Furthermore, repair goes far beyond the activity itself. Dealing with the broken objects and trying to repair them in the Repair Café opens up a wide field of social issues, such as, the quality of life in the local neighborhood, saving natural resources, and also the inclusion of excluded people in the social life of Repair Cafés.

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The Enablers and Barriers to Circular Economy Business Practices: Evidence from Businesses in Europe

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Abstract

The circular economy concept has garnered significant attention among academics, governments and the general public alike, as a potentially compelling solution to spiralling waste management problems and rampant resource use. Various interventions have been launched, including several at European Union level, aimed at promoting the transition to circularity, and examples of business showcasing circular processes seem to be steadily increasing across the globe. But while the nascent academic literature on circularity across various disciplines has made some inroads to defining circularity and to describing good practice, there is little by way of measurement or systematic analysis of the key factors that may enable or hinder the uptake of circular economy business models. The aim of this paper is to empirically-assess the enablers and barriers to business circularity, as well as the policies that might help facilitate the transition towards more circular business models. To this end, we conducted interviews with 107 high-level executives from European businesses, across several key sectors like manufacturing and construction. The interview covered various aspects related to respondents' awareness and concern for issues related to the circular economy, efforts to implement circular economy business practices, the key drivers and barriers in this regard, as well as the role of policy at the local and supranational level. Our results indicate that, even among the greener examples of European business, where recycling and reprocessing of components is present, the use of virgin raw materials as inputs is still largely prevalent. When it comes to the enablers and barriers, the results underscore the importance of business leadership and direction from senior executives in terms of driving the shift towards circularity. We also find evidence that a disconnect exists between the environmental and business arms of these firms, which may hinder the shift towards circular economy business models. In addition, respondents believe that consumers are largely indifferent towards key circular economy product characteristics like reparability and recyclability, which may discourage businesses in their efforts to close the loop, although the perceived importance of quality and durability may assist in creating a business case for prolonging product lifespan. Finally, respondents see a minimal role for government policy, although the introduction of quality standards for reused/recycled raw materials and minimum reused/recycled input requirements emerge as the key policies which may assist in promoting circular business. The results have several important implications, notably in terms of focussing policy efforts on encouraging more circular input usage across businesses, while underscoring the need for greater integration of environmental and business roles within entities.

Keywords: Circular Economy, Enablers, Barriers, Circular Economy Policies, Europe

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1. Introduction

The circular economy has emerged as one of the most salient ideas in public discourse around the world, with private individuals, governments and businesses alike embracing this concept to varying degrees. The need for a complete overhaul of existing linear practices has never been more stark – the World Bank estimates that, under the status quo, global waste levels will increase by a massive 70% by 2050 relative to current levels (Kaza et al, 2018). The environmental and economic consequences of such trends are significant, particularly if much of this waste is non-recyclable. For example, Jambeck et al (2015) find that up to 12.7 million metric tonnes of plastic waste enters the ocean globally every year, while Beaumont et al (2019) estimate that the environmental, social and economic costs of marine plastic is equal to around US$2.5 trillion per year as a result of damages to fisheries, aquaculture and oceanic recreational activities, among many other impacts.

At the other end of the supply chain, resource use and exploitation is also a perennial global concern. Schandl et al (2017) find that materials extraction across the world has grown exponentially from 22 billion tonnes in 1970 to 70 billion tonnes in 2010, despite a slowdown in both population and economic growth over the same period. This invariably creates significant pressures on the sustainability of natural resource stocks over the coming years. For example, Mekkonen & Hoekstra (2016) find that around 4 billion people around the world live under severe water scarcity for at least one month every year, while Henckens et al (2016) report that key minerals like antimony and zinc are at severe risk of depletion within decades unless decisive policy interventions are not implemented.

Within this context, it is important to understand how the circular economy can help to alleviate these natural resource and waste challenges through tangible, actionable measures. While various campaigns have been launched in order to encourage households and individuals to adopt more circular practices in their daily lives, the role of private business in closing the loop cannot be understated. For example, in the European Union only 8.5% of total waste generated per year is attributable to households (Eurostat, 2016), with the remainder split between a variety of business sectors, particularly construction (36.4%), mining and quarrying (25%) and manufacturing (10.3%). Furthermore, factors like product design (Bocken et al, 2016), extended producer responsibility (Gu et al, 2017) and supply chain management (Genovese et al, 2017) have all been widely identified as key in driving the shift towards the circular economy, with the bulk of the responsibility in the hands of business and private enterprise. Thus, it is important to understand the various internal and external factors that may help or hinder businesses in their attempts to undertake practices that are more in line with the precepts of a circular economy.

The aim of this paper is to understand the key enablers and barriers to the adoption of circular business practices, as well as any policies that may assist in closing the loop. To this end, we conduct interviews with 107 high-level business executives representing a variety of European enterprises across several industries like manufacturing and transportation. The interview covers various aspects related to respondents' awareness and concern for issues related to the circular economy, efforts to implement circular economy business practices, the key drivers and barriers in this regard, as well as the role of policy at the local and supranational level. The key research questions that this paper seeks to address can be summarised as follows:

- What are the main circular economy activities that our sample of European businesses currently undertake?
- What are the key enablers and barriers to business circularity in our sample?
- Which policies would assist in closing the loop among European businesses?

This paper contributes to the recent literature on sustainability and circularity among business. While several authors have looked at the role of consumers and their perceptions regarding the circular economy (e.g. Lakatos et al, 2016; Borello et al, 2017; Hazen et al, 2017), a growing body of work is increasingly focussing on the role of business in this transition. Lewandowski (2016) provides a synthesis of the key characteristics that make up a circular economy business model, including elements like take-back systems, closed-loop product design and servitisation, while Urbinati et al (2017) classify such business models according to the degree to which circularity is adopted within the customer value proposition and long the value network.

And yet, despite the obvious importance of identifying the various ways in which businesses can adapt their practices in order to become more circular, it is also imperative to understand the various factors that may assist or inhibit such changes. In this regard, a closely-related paper to ours is by Kirchherr et al (2018), who conduct a survey across 153 businesses, 53 government officials and consultations with 47 experts across academia, NGOs and business, in order to understand the key barriers to the circular economy. The findings show the emergence of two key types of barriers, namely cultural (e.g. lack of consumer interest/awareness, company culture) and market-based (e.g. high upfront investment costs, low prices for virgin raw materials) factors. In another related paper, Pheifer (2017) conducts nine interviews with business representatives and thought leaders in order to source their opinions on what could be key barriers and enablers to circular business models. The author distinguishes among three levels of enablers and barriers, namely micro, meso and macro factors. Micro-level enablers include circular key performance indicators (KPIs) and circular training, at the meso-level take-back systems for resources was mentioned, while at the macro-level mandatory eco-design and circular public procurement were mentioned as potential enablers. In terms of barriers, micro-level factors include lack of knowledge and skills and non- circular product design, at the meso-level the lack of data and transparency along supply-chains was flagged as a possible inhibitor, while at the macro-level low prices of virgin raw materials and institutional barriers were identified as barriers to circularity.
In turn, Rizos et al (2016) focus on enablers and barriers to circular economy business models among SMEs, using a sample of 30 case studies derived from the GreenEcoNet platform. The findings suggest that several factors like supportive company culture, collaborations across value chains, staff know-how and customer demand for green products helped to facilitate the implementation of CEBMs, while lack of capital, lack of awareness regarding benefits of circular economy business models, punitive regulations and distortive tax policies hinder the adoption of such models among SMEs, echoing findings from the Flash Eurobarometer 441 (2016) on the perceptions and activities of European SMEs with regards to the circular economy. The importance of contextual or external factors is also cited in Witjes & Lozano (2016), who focus on the potential

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for sustainable public procurement to induce greater business circularity by linking contracts to specific features of sustainable business models and practices.

2. Methods

2.1 Interview Design

In order to understand the key enablers and barriers to business circularity, we designed and administered an interview with European businesses across a wide variety of industries. The interview questions were broadly split into four sections. The first section contained various questions related to business and respondent demographics, including size and industry, while the second section sought to capture the key circular and environmental activities and initiatives that businesses were currently undertaking or planning to undertake within the short term, including their use of reused or recycled inputs and their waste disposal practices. In turn, the third section looked at teasing out different enablers and barriers to business circularity, including the key stakeholders in business and environmental strategy as well as their perceptions regarding customer values. Finally, the interview concluded by asking respondents to indicate the extent to which a variety of existing and proposed policy options would assist in the drive towards circularity, from the EU's Circular Economy Action Plan to waste or landfill taxes. Given the international nature of the research, questions were distributed via email to the various business and enterprise networks that are affiliated with the R2Pi – The Route to Circular Economy Horizon 2020 project and its partners. The majority of questions were closed-ended in order to ensure brevity, and the questionnaire took approximately 15 minutes to complete. We specifically targeted high-ranking executives within each organisation, with a particular preference for Environmental, Sustainability or Circularity Officers wherever possible due to the subject matter. Ethical approval for the research was granted by the University of Malta's Research Ethics Committee (UREC) in October 2017, and the interviews were distributed between April and June 2018.

2.2 Data & Analysis Tools

In total, we received 126 responses, although this figure dropped to 107 due to data omissions and incomplete responses. The majority of respondents (25%) work as Environmental or Sustainability Officers within their organisation, followed by managing directors (17%) and sales and marketing personnel (15%). Figure 1 below shows the country breakdown of responses, with the majority coming from Germany (28%), followed by Poland and the Netherlands (10% each), which attests to the wide dispersion of firm respondents. Figure 2 provides a breakdown of the respondents' key industrial sectors. As seen from the diagram, the leading sector captured by this interview is manufacturing (27 respondents), followed by construction (16) and ICT (14). Furthermore, Figure 3 looks at the size distribution of the businesses involved in our interview, based on self-reported annual revenue. The majority are classified as either micro or small (45% combined), with another 40% of responses from large businesses. This distribution is in part reflected in the scope of business activities reported in the interview, with 32% of respondents operating on a global level, followed closely by another 31% whose business scope is national and 16% who operate on a regional level. On average, the businesses in our interview have been in operation for almost 49 years, which indicates that our sample largely consists of businesses that are well-established within their respective industries and have been in operation for a relatively long period of time, as opposed to start-ups. In turn, almost 60% of firms are primarily involved in Business-to-Business (B2B) sales with other companies or retailers, with only 16% selling directly to households.

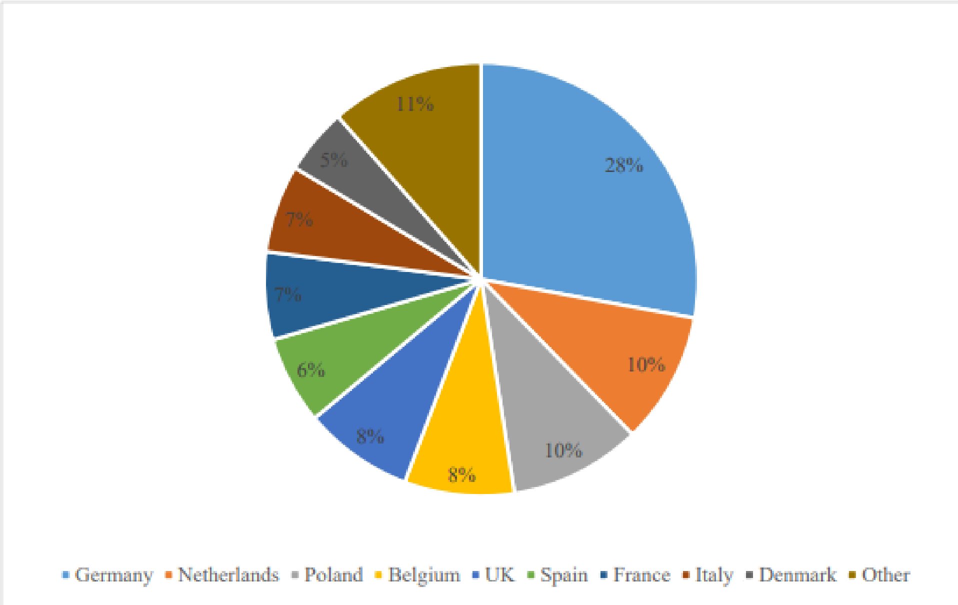

Figure 1: Geographical distribution of businesses

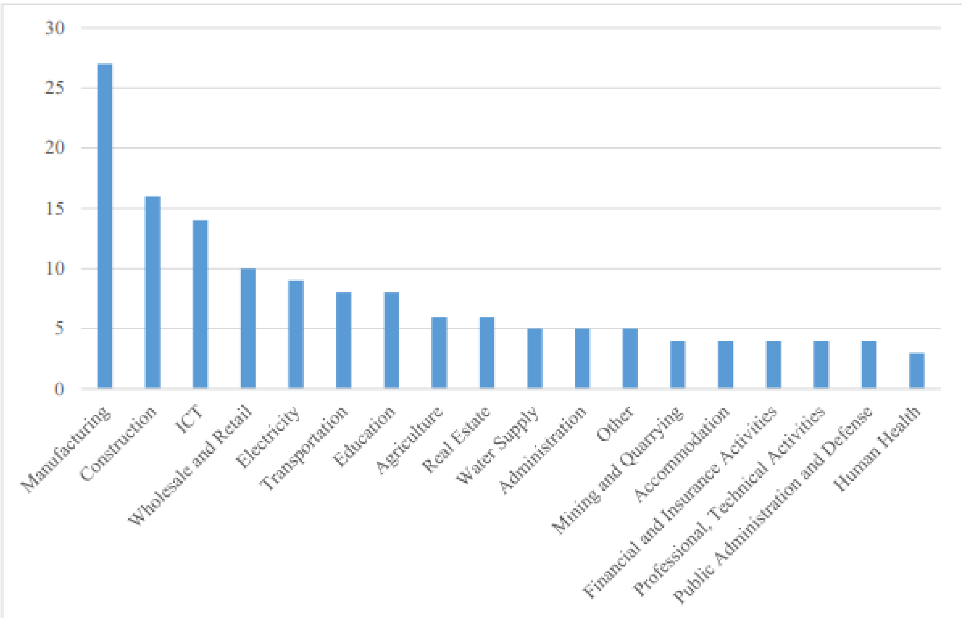

Figure 2: Industrial Sectors of Respondents

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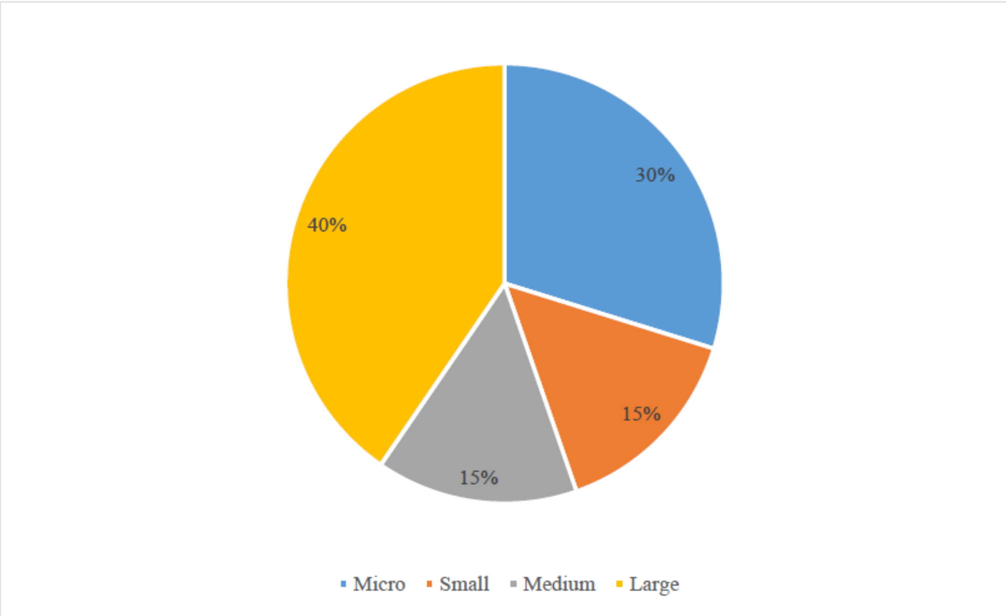

Figure 3: Size Distribution of Respondents

Given the relatively small size of our sample, this paper will largely focus on descriptive statistics in order to analyse the key findings that emerged from the interviews, and how they relate to our research questions. The closed nature of most of the interview questions also allow us to utilise some simple correlation analysis in order to analyse relationships between various circular behaviours and different business characteristics.

3. Results and Discussion

2.3 Circular Economy Activities

The interview included a number of questions related to the circular economy impacts and practices of our sample. As seen in Figure 4, the biggest self-reported negative environmental impact of businesses in our sample was on climate change, closely followed by waste management and air pollution, although in all cases respondents believe their overall impact to be low. A closer look at the data reveals that businesses within the transportation sector reported the highest negative environmental impact, particularly when it comes to waste management and climate change, followed by the electricity sector and wholesale/retail enterprises. By contrast, we find very little variation in environmental impact across different business sizes, with micro enterprises recording slightly lower waste impacts relative to the rest, but conversely higher noise pollution. This is shown below in Table 1. The overwhelming majority (94%) of respondents stated that environmental considerations are either ‘Extremely Important’ or ‘Very Important’ for them, which is unsurprising given the nature of the interview coupled with the roles occupied by many of the respondents, and tallies with the low average impacts observed in Figure 4.

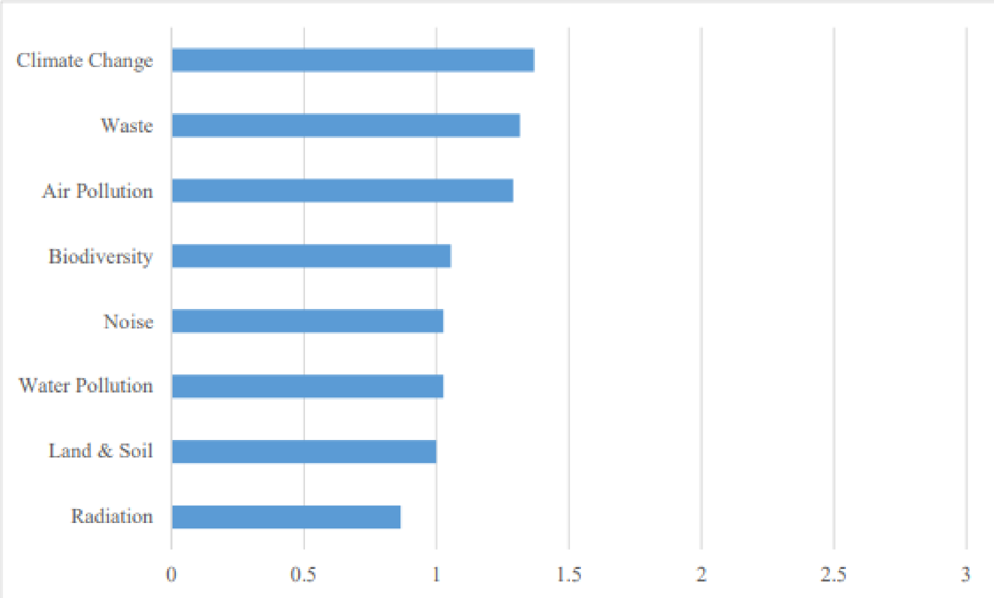

Figure 4: Self-Reported Negative Environmental Impacts of Respondents

Table 1: Average Environmental Impact by Business Size

	Water	**Waste**	**Land**	**Biodiversity**	**Climate Change**	**Radiation**	**Noise**	**Air**
Large	1.1	1.6	1.2	1.2	1.6	0.9	0.9	1.4
Medium	0.8	1.4	1.0	1.3	1.2	1.3	0.8	1.0
Small	1.0	1.4	0.8	0.8	1.2	0.8	1.2	1.4
Micro	1.1	0.9*	0.9	1.0	1.4	0.7	1.3**	1.5

Notes: Figures are mean values on a 5-point scale, ranging from 1 (Very Low) to 5 (Very High).

** denotes that the difference in mean value, compared to the other means, is statistically-significant at the 5% level;

* denotes that the difference in mean value, compared to the other means, is statistically-significant at the 10% level.

A number of follow-up questions were asked to further probe the circular economy credentials of the sample. An average of 29.8% of respondents' energy requirements were reportedly generated from alternative sources like solar or wind power, which is higher than the EU average of 17% and the target of 20% by 2020 (Eurostat, 2018). In turn, almost 60% of raw material inputs originated from virgin resources, followed by over 31% from recycled materials. As seen in Table 2, the electricity sector utilises the highest proportion of virgin inputs

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(80.5%), unsurprising given the nature of the business, followed closely by the ICT sector (56.4%) and the manufacturing sector (54.3%). In turn, the construction sector leads the way when it comes to the use of recycled inputs (44.6%), while both the electricity and transportation sectors reported the highest use of reprocessed inputs. This indicates that although the businesses in our sample are attempting to close the loop in terms of input usage, there is still room for improvement, particularly when taking into account the high level of environmental concern and awareness expressed by our sample, which may not be reflective of all businesses.

Table 2: Use of Inputs and Disposal of Waste among Respondents

Sector	**Virgin Inputs**	**Recycled Inputs**	**Reprocessed Inputs**	**Mixed Waste**	**Recycled Waste**	**Sold Waste**	**Reprocessed Waste**
Manufacturing	54.3%	37.8%	18.5%	11.0%	48.7%	32.4%	36.4%
Construction	45.7%	44.6%	18.0%	8.9%	31.4%	38.7%	56.5%
ICT	56.4%	35.5%	20.6%	30.6%	36.1%	18.5%	11.6%
Wholesale & Retail	46.2%	37.8%	20.5%	11.2%	61.5%	35.0%	14.5%
Electricity	80.5%	35.3%	26.7%	17.3%	39.0%	48.0%	63.0%
Transportation	39.5%	25.6%	26.6%	9.0%	53.8%	27.5%	11.0%

We also compare the mean use of virgin, recycled and reprocessed inputs across different business sizes, using a Kruskal-Wallis test. The results, shown in Table 3, reveal that we have statistically-significant differences across size when it comes to the use of recycled and reprocessed raw materials. In fact, a closer look at the data suggests that micro enterprises have the highest rate of use for recycled and reprocessed raw materials, with the difference relative to large firms being statistically-significant at the 5% level for recycled inputs (p=0.022). Thus, in our sample micro enterprises are more likely to utilise recycled and possibly reprocessed raw materials, which may be indicative of the fact that smaller firms are increasingly aware of the potential cost-benefits to be accrued from using secondary raw materials (e.g. Rizos et al, 2016).

Table 3: Circular input use - comparison by business size (Micro vs. Small vs. Medium vs. Large)

Circular Activity - Inputs	**Kruskal-Wallis chi-square statistic**
Virgin raw materials	1.595
Recycled raw materials	8.633**
Reprocessed raw materials	5.294*

Notes: **denotes statistical significance at the 5% level; *denotes statistical significance at the 10% level.

Matters are considerably more encouraging when it comes to waste management, since a reported 50.2% of total waste generated by respondents is, on average, separated for recycling, with a further 30% reprocessed within the business. In addition, an average of one third of all waste generated by respondents is sold off to third parties, which underscores the growing recognition among businesses of the value of waste as a potential revenue- generating resource. As seen in Table 2, the ICT sector reported the highest proportion of mixed waste (30.6%), which underscores the need to target waste separation efforts at service-based enterprises given their importance to the EU's economy. By contrast, wholesalers and retailers recorded the highest proportion of recycled waste (61.5%), while the electricity sector came out on top in terms of both the reprocessing of waste (63%) and the proportion sold off to third parties (48%). When it comes to waste management according to business size, we find no statistically-significant differences across businesses in each domain, with the only exception being that micro firms generate somewhat more mixed waste than the others (35%; p=0.0692).
These results have interesting implications for the circular economy within the EU. Firstly, the large proportion of waste that is recycled or reprocessed bodes well for efforts aimed at reducing the amount of mixed waste disposed at landfills, particularly in countries where land availability is at a premium. Secondly, the sale of waste to third parties can further encourage businesses to take waste management seriously, while also opening up avenues for circular economy business models and opportunities based on these activities, either within existing businesses or through the formation of new businesses in areas like waste transportation and secondary marketplaces. Thirdly, the apparent gap between business' efforts to recycle/reprocess waste and their actual use of inputs made from recycled or reprocessed materials points towards a potential dissonance between the proliferation of circular economy principles in the field of waste management versus procurement and/or manufacturing. This could be due to a number of reasons:

- Waste disposal at landfills often carries a charge for commercial entities, thus creating a financial incentive to recycle/reprocess waste. Such punitive measures are not in place when it comes to the use of virgin raw materials;
- Recycled/reprocessed waste can be sold off to third parties, which in turn generates revenue, creating another financial incentive. By contrast, recycled/reprocessed raw materials are often the same price as virgin materials, in some cases more expensive;
- Manufacturing of certain products may often require the use of virgin raw materials due to quality

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standards and/or regulations which cannot be reached by recycled or reprocessed inputs given current technological limitations (without incurring prohibitive costs);

- Lack of independent, objective quality standards for secondary raw materials may hinder their uptake and foster doubts among manufacturers and customers;
- The general perception regarding recycled/reprocessed inputs is still negative in many cases.

3.1 Enablers and Barriers

We now turn to the factors that facilitate or hinder the pursuance of circular economy business activities among our sample. Respondents were asked to evaluate the relative importance of a number of stakeholders and issues in their organisation's daily business activities, plans and processes. This was followed up by another question whereby respondents were asked to evaluate the influence of the same list of stakeholders and considerations, this time in relation to environmental practices within the business. This approach was adopted since the shift towards circular economy business models requires a complete re-evaluation of existing (often linear) business operations, over and above sustainability or pro-environmental policies. The results of both questions are shown below in Figure 5. When it comes to business activities, the three most important influencers cited are the Chief Executive Officer (CEO), the owners and general economic conditions. In turn, the respondent themselves, which is unsurprising given the large proportion of environmental officers among our respondents, the CEO and the government are the leading influencers within the sphere of environmental activities.

A number of interesting observations can be derived from these results. Firstly, the importance of the organisation's leadership in helping to enact circular economy business models cannot be overstated, given their central role in both business and environmental activities among our sample, and can therefore be both an enabler and barrier to business circularity. Secondly, it is clear that the government has a much larger impact on environmental activities than overall business planning, which indicates that public policy has an important role to play in pushing the circular economy agenda. Thirdly, the fact that respondents play such an important part in terms of environmental activities within their organisation, but have a comparatively minor impact on overall business activities on average, points towards an apparent disconnect between environmental and business operations. This may hinder the shift towards circular economy business models since a successful transition requires both elements to work in tandem with one another towards the same overarching objectives, rather than as disparate entities, as outlined in Park et al (2010) when assessing three case studies from China's ICT and electronics sectors. Thus, the results suggest that more needs to be done in order to integrate environmental and/or sustainability issues as a central part of business planning.

To complement these answers, a separate question was included where respondents were asked to assess the importance of environmental considerations (e.g. renewable energy use, recycling, etc.) in three key business domains, namely purchasing goods or inputs from suppliers, marketing and selling of goods and services, and transportation or logistics. The results, shown in Figure 6, indicate that the highest average score was for marketing and selling, followed by purchasing inputs and transportation. Therefore, the findings demonstrate that overall, environmental issues are of low to medium importance across all business domains, which ties in with the earlier discussion surrounding the disconnect between environmental and business activities, which may hamper the drive towards business circularity.

In addition, the interview also asked respondents to rate the extent to which they believe that their customers value a number of product characteristics. The responses are shown in Figure 7, with the top three valuable characteristics being quality, price and durability, with the latter being directly related to circular economy principles. By contrast, the other characteristics that feature heavily as part of circularity, namely environmentally- friendly production, reparability, recyclability and upgradability all obtained very low scores. Thus, these results suggest that perceived consumer indifference towards key circular economy product features may also act to delay the transition towards more circular business models, given the lack of demand, particularly since as mentioned earlier respondents believe that environmental considerations are largely confined to marketing and selling. Nonetheless, the perceived importance of both quality and durability also helps to create a business case for circular business models that are based on prolonging the product lifespan as much as possible. This also underscores the potential importance of independent quality standards for reused and/or recycled materials to assuage any customer doubts regarding quality, although this must clearly not come at the expense of higher product prices.

Respondents were also asked to indicate the extent to which they intend to recommend that their business implements a number of initiatives related to environmental management and the circular economy over the coming three months. The results are shown in Figure 8. As seen below, the initiative that obtained the highest recommendation score was the implementation of a business model that adheres closer to the circular economy when it comes to business planning, followed by environmental training programme for staff and the acquisition of more information regarding the circular economy. These responses underscore the fact that businesses across Europe are increasingly aware of the need to become more circular in their operations due to the various benefits emanating from such practices, and are actively looking to enact such changes. What is interesting is that those businesses where we observe the highest discrepancy in terms of the respondent's environmental and business planning influence are also more likely to recommend such an initiative within the next 3 months ($t=2.14$; $p=0.043$). This emphasises our previous point regarding the disconnect between business and environmental planning, since it suggests that organisations with the highest level of discrepancy are also those that are most aware of the potential benefits of becoming more circular, possibly due to the lack of such initiatives at present. In fact, in our questionnaire a zero score denoted that such initiatives were already in place, which further highlights the lack of such circular practices among businesses with high levels of disconnect between business and environmental planning. Another point that can be drawn from these results is the need for more staff training on environmental or sustainability matters, which is imperative since enacting the necessary changes to a business model will require both acceptance and knowledge from existing staff members in order to support this transition, and tallies in particular with the results in Pheifer (2017). In addition, despite the proliferation of the circular economy concept across the world in recent years, there is clearly still a need for further knowledge and information on the circular economy and related business models, at least at the business level, in line with Pheifer (2017) and Rizos et al (2016), who also find significant gaps when it comes to awareness regarding the circular economy and its potential benefits. Finally, the interview was also aimed at understanding which policy tools would be most effective in facilitating the shift towards circular economy business models. To this end, respondents were asked to assess the influence of a number of policy interventions on their business operations. The results are depicted in Figure 9. Only three policies

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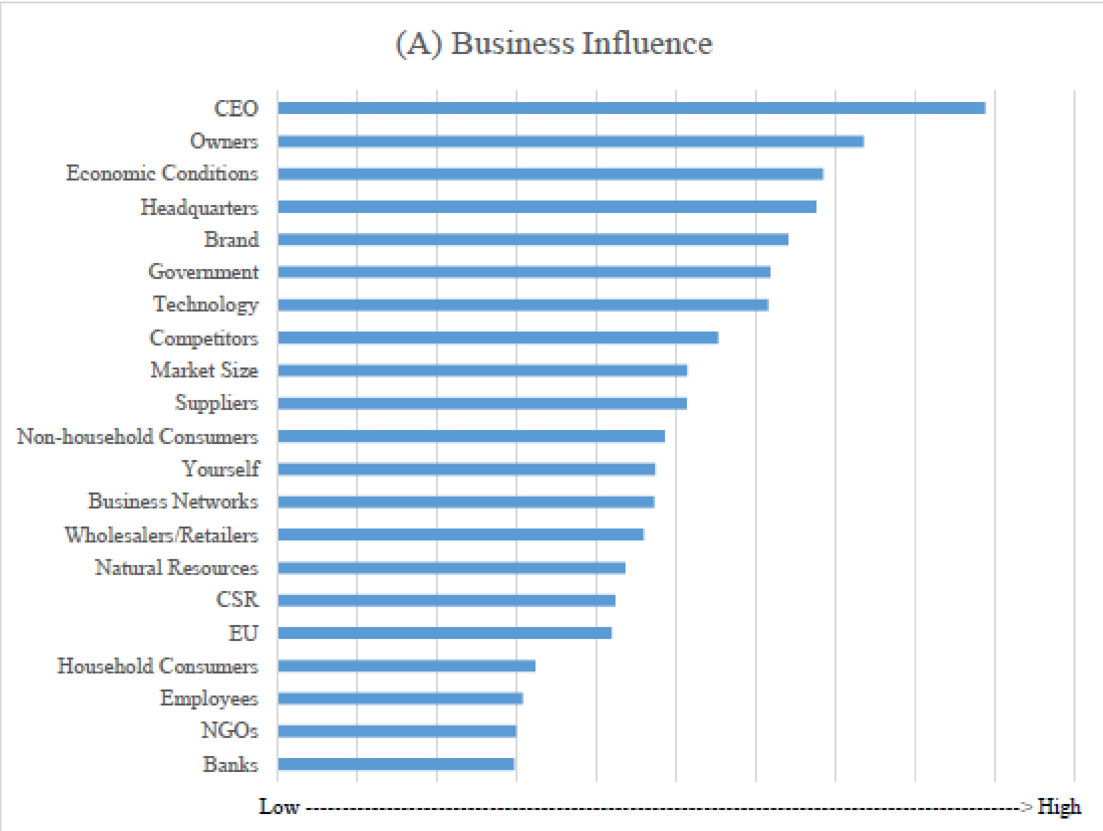
obtained a score that was either above or on the midpoint, namely circular economy policies, quality standards for reused/recycled materials and minimum reuse/recycling input requirements. While it is difficult to interpret the choice of circular economy policies due to its generic nature, the relative influence of quality standards echoes earlier findings regarding the importance of such standards in order to encourage greater use of reused or recycled materials by businesses without forgoing quality, which is a key consideration for customers. Minimum reuse/recycling input requirements also emerged as an important policy option, which suggests a greater role for more forceful government intervention in the drive towards greater business circularity. Nonetheless, it is important to note that all other policy options were given low scores by respondents, indicating that they perceive most existing policies to have limited impact on their business decisions. This may in part reflect general antipathy towards traditional government policies like taxation and subsidies, but may also be due to a perceived need for more innovative interventions to assist business, particularly when it comes to circularity.



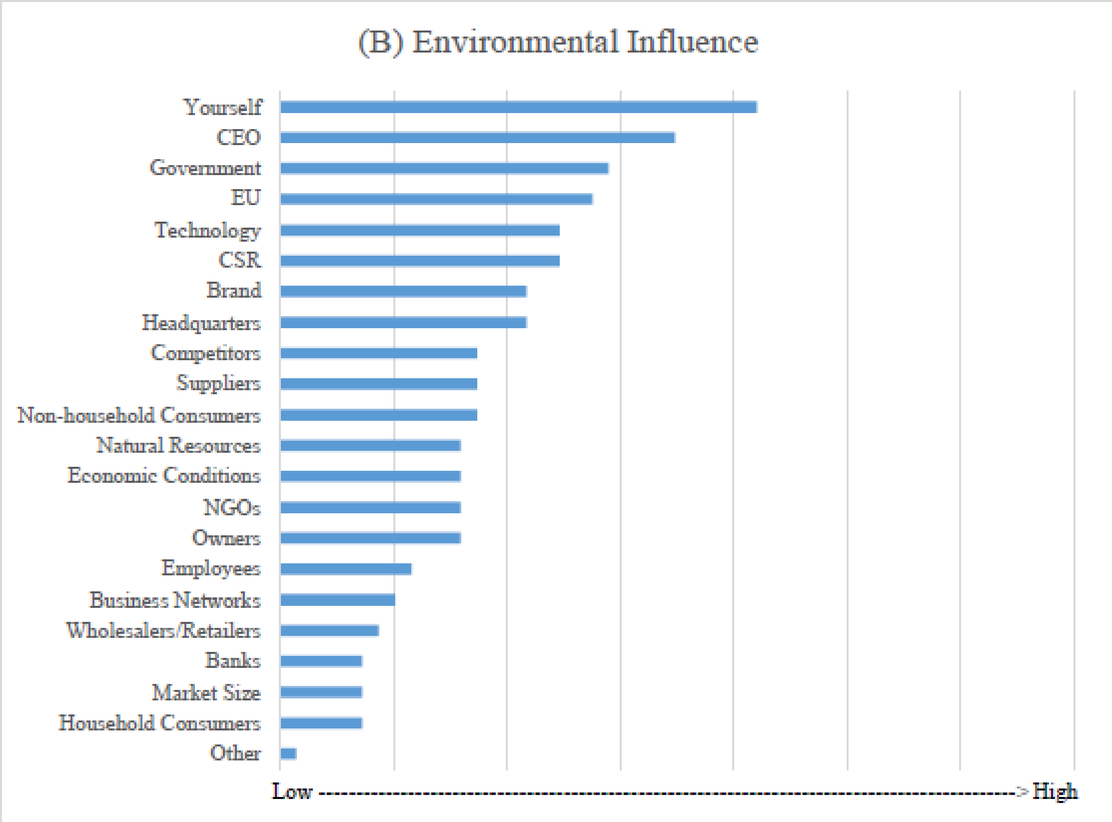


Figure 5: Influence of Various Stakeholders and Considerations on Business and Environmental Activities

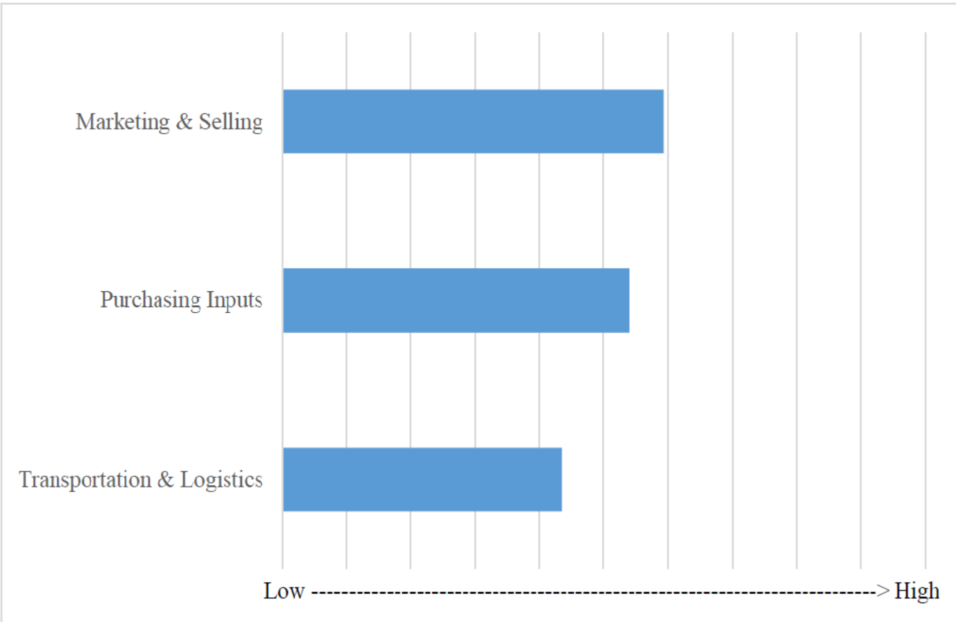


Figure 6: Importance of Environmental Considerations across Business Domains

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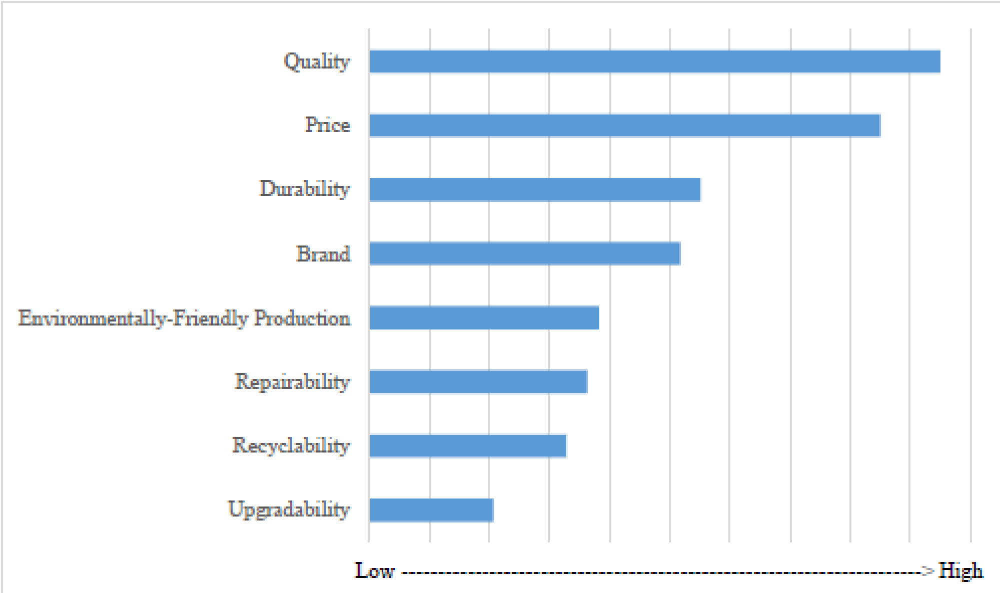

Figure 7: Perceived Importance of Various Product Characteristics to Consumers

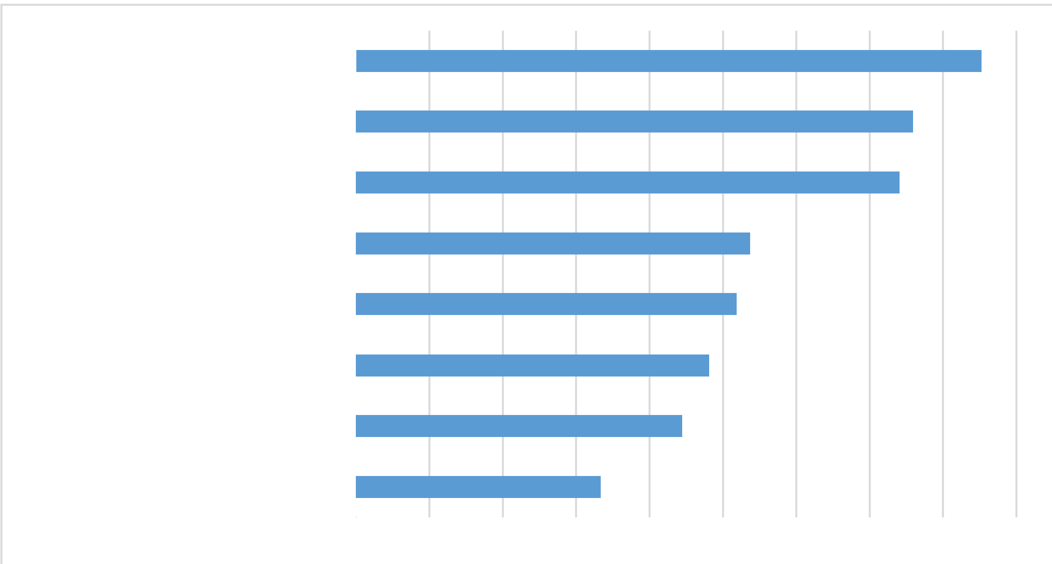

Figure 8: Willingness to recommend various environmental initiatives over the next 3 months

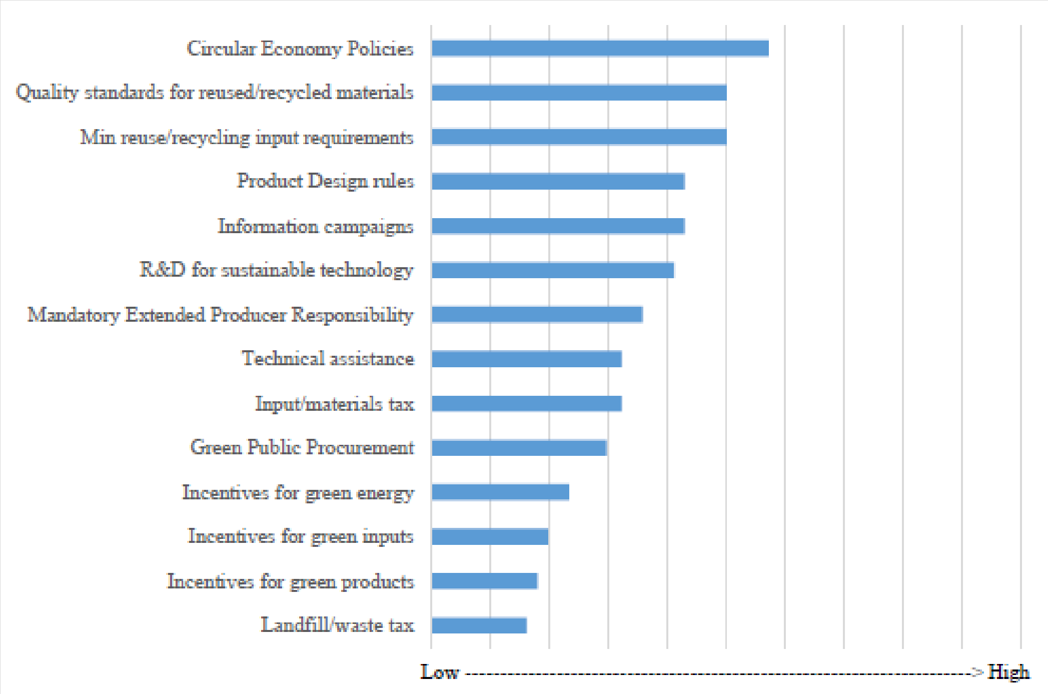

Figure 9: Influence of Policies on Business Operations

4. Conclusions

This paper has sought to understand the circular economy practices and behaviours of businesses in Europe, together with an attempt at analysing the key drivers and barriers that may influence their activities. To this end, we designed and administered a set of closed-ended interviews among a sample of 108 business of all sizes from across Europe, spanning several countries and economic sectors. The results showed that circular waste management practices among European businesses are increasingly prevalent, particularly when it comes to waste separation and recycling, with a significant proportion of firms also actively engaged in selling off their waste to third parties. By contrast, the use of secondary raw materials (recycled and/or reprocessed) is still somewhat lagging behind, meaning that there is potential for considerable improvement in this area.

When it comes to the enablers and barriers to business circularity, respondents cited the CEO as being the among the key players both when it comes to business strategy as well as environmental planning. Nonetheless, we also found that there is a significant discrepancy between the importance of the respondent, often the environmental officer or representative, when it comes to environmental planning, and his/her centrality to business strategy. This may prove to be a significant barrier to business circularity, since it requires the alignment and integration of both business functions in order to properly succeed and bring about real change. The fact that respondents mainly perceive environmental considerations to be important for marketing and selling further emphasises this point, and may be indicative of a wider issue when it comes to actively incorporating the circular economy into all aspects of business operations. In turn, we also found that respondents believe that their customers are mainly concerned with product quality and price, with little regard for key circular economy features like reparability, recyclability and upgradability, although both quality and durability featured highly in their estimation, both of which have clear links to circular economy practices. In

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terms of future plans over the coming months, respondents were most likely to recommend the introduction of more circular business models, environmental training for staff and the acquisition of more information related to the circular economy. Finally, we also found that there is a general antipathy towards public policy in order to assist in the shift towards more circular business, although the EU's Circular Economy Action Plan, quality standards for secondary raw materials and minimum reused/recycled input requirements emerged as the leading policies.

The results underscore the importance of senior management and leadership in driving forward the transition towards a circular economy within businesses, together with the need for greater integration of environmental considerations in business operations. Furthermore, consumer demand can act both as a barrier and enabler to increased circularity due to a perceived lack of importance attributed to key product characteristics like reparability and recyclability on the one hand, and a high value placed on durability and quality on the other hand, which suggests that business models based on these latter characteristics would be more likely to succeed. In addition, although government policy is perceived to be important in encouraging more pro-environmental activities, the general lack of influence of existing policies points towards a need for more innovative initiatives, including quality standards for reused and/or recycled materials.

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Towards a monitoring framework for measuring progress in Circular Economy

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1. Introduction

There has been a growing realisation that pressing environmental problems and economic instabilities ask for a fundamental change in our current patterns of production and consumption. The transition towards a circular economy (CE) has been proposed as a means for operating industries within the carrying capacities of planet earth and for advancing more sustainable forms of capitalism (Ekins 2002; Greyson 2007; WBCSD & Horn, 2010). CE denotes the idea of creating closed-loop systems of resource use through production and consumption models wherein materials and components can be used over multiple lifecycles with the highest value retention over these consecutive cycles, and as such stands in sharp contrasts to the dominant economic paradigm with its linear take-make-dispose production and consumption model.

Moving towards CE can be viewed as a process of socio-technical transition. Historically, CE has been applied at limited, and local scale, for example in eco-industrial parts. As Blosma and Brennan (2017) & Reike et al. (2018) have shown, the concept of CE has undergone several stages of development before it has gained momentum around 2012 and found its way into policy programmes around the globe as one of the key strategies linked to overcoming grand societal challenges of our time including energy use, climate change, urbanisation, land use, and biodiversity conservation (EU reports).

CE has hence been ascribed high potential, yet arguably it being seen connected to various fields in transition studies by authors of a multitude of disciplines bears evidence to the concept scope and complexity. If CE was indeed to become understood as a new economic model underlying all production and consumption processes it demands a complete technological and organisational reconfiguration of global supply chains along with new consumer, market and financial institutions. The complexity in defining CE and its scope makes the implementation challenges particularly high for the many non-expert stakeholders currently confronted with CE.

In this context, a number of academic articles have put forward that research into CE measurement is one of the key fields to drive forward CE implementation in practice and help guide the multitude of actors involved in CE in various processes from decision-making to evaluating effects and performance of CE practices. Saidani et al. (2019) argue that it is "commonly acknowledged that to promote CE, the introduction of monitoring and evaluation tools like indicators to measure and quantify this process becomes essential" (p.544).

While CE measurement is a recent field, Figge et al. (2018) outline that a large body of 'circularity' metrics literature has already emerged which are however very diverse. Many can be regarded as under-developed or limitedly suited as they are borrowed from other disciplines and therefore not specifically tailored to CE and its principles such as waste, emission metrics and the variety of efficiency metrics. Established methodologies like MFA focus on quantity of retained materials and cannot measure the value and quality retained in materials or favour absolute refusal of resource use over efficient use.

Regardless these shortcomings, the main issue in the CE measurement and monitoring literature is that the established metrics can merely describe the effects of CE practices and outcomes of CE processes, but they are not suitable for describing the transition process towards CE. Yet it is precisely this long-term nature of societal transitions which represents a challenge and complicates understanding and recording progress in CE development. Different literature streams, among them the innovation systems literature, have established that it needs a process of decades, if not several generations for completing a transition resulting in the overturn of the existing prevailing socio-technical system.

According to this literature, a formative and a growth phase of the transition process can be observed. CE is expected to be in the formative phase for several decades. In this phase a focus on outputs is suboptimal for measuring progress as significant effects or impacts cannot be established because the necessary critical implementation volume for measuring effects has yet to be attained – at least when it comes to measuring progress at the level of sectors or the economy as a whole.

This also relates to the delayed and dispersed nature of environmental impacts which can which makes it generally difficult to measure such impacts accurately. In sectors with products with longer lifetime, for example construction, it can take several decades before a product proceeds from one lifecycle stage to another so that the quantity and quality of the retained materials becomes measurable (Korhonen et al. 2017, Jacobi et al., 2018). Generally, the time lags between activities carried out by actor groups and outcomes indicating CE development can be assumed to be quite large in the formative phase.

Therefore, exclusive use of assessment and performance metrics problematic. We argue that relying exclusively on those indicators risks rendering the formative phase of development a 'dark phase'. Particularly, in a phase where substantial effects or impacts are not measurable in the economy as a critical mass of materials has yet to be attained, they offer little perspective of measuring CE despite activities towards CE being already undertaken in the economy and progress being traceable in of changing system functions/mechanisms/processes.

We conducted a review of 482 articles according to various categories (results exist and can be shown but are not included in this draft) which shows that indicators can measure performance and outcomes at various scales (micro, meso, macro) but they are focused on the circular economy implementation rather than the processes that lead to the development of CE. Therefore, an advance in application of those frameworks and methods for CE is central which can contribute to depicting advance in CE in both phases of development. A more holistic measurement framework focused on CE development processes has also been called for by the EU, the EEA (ref) and by various scholars (Jacobi et al., 2018; Cobo et al., 2018; Saidani et al., 2017, 2019).

Our paper aims to provide an attempt at developing such a guiding framework and heuristics for CE progress measurement by means of with monitoring system processes. In line with Korhonen et al (2017) we show that the CE transition cannot be fully understood through a focus on material flows, emission and waste indicators. After all these are focused mainly on the technical aspects of system reconfiguration, and there is a need to complement existing methods with analytic methods which can describe CE formation in a wider temporal, spatial, cultural and institutional context. We propose that innovation sciences literature can serve to address the shortcomings of CE measurement and indicators and reveal developments in the 'dark

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phase' of the CE transition process.

Departing from this literature, the transition towards CE can be understood as a set of technical and social innovations which combined induce change processes that overturn the present linear socio-technical production and consumption system. A strength of this literature is that it can capture the current state of developments in a given system and based on this analyses, defines processes needed to take place before the system can move to a new stage. Therefore, it allows to measure activities and intermediate outcomes rather than final effects or end- states. For building our framework, we infer indicators from the 'functions of innovation systems' approach (Hekkert et al. 2007) and show how this approach used to measure key activities in an innovation system in various phases of its development can be adapted to function as important contribution to capturing CE progress.

Section X serves us to further illuminate the knowledge gap in CE measurement and monitoring. We seek to make a separate contribution through this comprehensive review which illuminates other aspects than existing CE reviews. For example it shows that besides a lack of frameworks focused on CE processes, CE measurement and monitoring at macro level is generally not as developed as assumed by leading scholars in the field based on their reviews (data exist, can be shown, but are not yet included in this paper draft). Section 2 provides the theoretical background on innovation systems theory that our framework is leaning on/into which are our framework is embedded. Section 3 introduces the framework and the three categories of key conditions of measuring progress in CE (at system level): capabilities, motivations and permissions. Finally, we demonstrate how the key elements of the framework can be complemented with existing disciplinary approaches and the concept of retained quality of resources in CE progress measurement (R-strategies). Section 4 provides first discussion of the framework, its practical application and its main limitations.

2. Technological Innovation System analysis as a starting point for Circular Economy progress monitoring

TIS analysis is normally used to describe the diffusion of an innovation within its surrounding system. TIS assumes innovations cannot develop in isolation but are embedded in a complex system structure consisting of actors, institutions and infrastructure surrounding the innovations. Interaction between these factors influences the diffusion of the innovation, and described with the help of so called 'system functions' in the analytic approach. In TIS, and other established innovation studies frameworks, the diffusion of innovations is described using an S-curve from pre-development, take-off (formative phase), to acceleration and stabilisation (growth phase).

It is assumed that the importance of functions differs over these phases of development and virtuous feedback loops can form among several of the key processes which can foster moving from one phase to another. In the growth phase the interaction dynamics achieved among these functions induce a certain directionality wherein particular approaches become the standard and reach a specific implementation volume (Hekkert & Markard, 2012). For papers with extensive outline of the TIS logic and the various analytic steps of Tis approach see for example Hekkert et al., 2007; Bergek et al., 2008; Hekkert et al., 2011. The TIS tends to be used in a meso-level context and is commonly applied to single technology. The approach has earned a solid reputation through being applied to forecasting a technological innovation trajectory. Amongst others it has been used by the Dutch government for identification of drivers, barriers in a given studied system, as a tool which also allows to deduce advice for fostering desired system developments. However, it has also been criticized for knowing only 'the way up', it's technological focus, and the limited applicability in transition context due to wider sectoral and system dynamics getting backgrounded in many TIS which have the study of single technologies as their starting point (Kivimaa & Kern, 2018) .

However, over the past years, TIS has seen a number of extensions and applications of researchers in new fields. For example, Kivimaa & Kern, 2018 have used the concept of TIS functions in order to study policy mixes in a transition context. We likewise show that TIS extensions allow placing the approach in a new context. In line with general call of scholars in transition and innovation studies to build on, extend, reconfigure existing frameworks to widen their applicability towards transition context (Geels at IST Conference, 2018), those recent advances of TIS have encouraged us to take the analytic approach as point of departure for progress measurement framework CE.

(In using TIS we address many of the shortcoming raised as lacking in the literature Its has a solid theoretical basis in innovation theory and can be complemented with other influential approach in the field (Markard & Truffer, X). It is congruent with CE in taking a system perspective (Geissendoerfer et al,, 2015; Kirchherr et al., 2017), and it allows to describe system change in terms of conditions and elements employed by actors in a specific context (X). The emergent nature of CE system is another reason for this choice as technological innovation systems (TIS) as an approach has a wide empirical evidence base for accurately depicting progress of innovation system formation which is the focus of the generic framework introduced in this paper ( )

3. A Circular Economy monitoring framework

Before introducing the framework, we acknowledge that any measurement and monitoring framework should clarify its understanding of CE as a concept. The Ce definition will significantly influence parameters that are likely to be taken into account and measured.

We depart from the definition coined by Kirchherr et al. (2017) of CE "as an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-in-dustrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. "

The definition matches the framework as its key elements are congruent with our framework: The system perspective ('economic system' and different 'level[s] ') (see 3.3.1), the process perspective (now and '' future generations') (see 3.3.2., 3.3.4.), and emphasis on different options to retain the value of resources in CE ('reuse, etc.') (see 3.3.3). From an innovation perspective, we define CE diffusion as a complex transition process over phases which includes different kinds of technological, social innovations

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contributing to change in the socio- technical system (note for Denise: compare with earlier versions). In taking this perspective we depart from the TIS analysis, as it tends to look at a system from perspective of specific desirable technological alternative.

The commonality in the vast set of different social and technological innovations underlying CE development at different system scales (from micro to macro) lies in their requirement to involve a variety of economic actors and societal stakeholders for reconstructing supply chains and value chains into new functional CE-based configurations. We therefore take an actor-centered perspective on the system and argue measuring progress in the CE means measuring the build-up of conditions for actors and agents to successfully innovate and diffuse CE products and services. We hold that capturing actors and their interactions with conditions in the system can reveal CE development similar as is attained through the actor analysis and functions analysis as conducted in TIS analysis. activities among the agents which are embedded in certain framework conditions lead to key system processes which help building up the system

3.3.1 Key system conditions

In our framework we depart from the idea of that CE as a system is made up of a multitude of societal actors and the infrastructure and institutions surrounding the innovations in the system. The first step of TIS analysis wherein an overview is gained of this basic system structure, is thereby taken for granted as a preparatory step for measurement and monitoring. At the core of our CE framework for the formative phase of CE development lies the investigation of the key system conditions affecting these structures which are inspired by the TIS the functions approach.

Based on the TIS, we assume that three system conditions influence how actors interact in the system and can make use of opportunities for CE development. They need to feel a need or “want to” drive forward CE, they need to be ‘able’ to engage in CE, and they need to “be allowed to” seize opportunities in the system for establishing CE practices.

For measuring the build-up of conditions for actors to successfully innovate and diffuse CE products and services we introduce three categories with different sub-indicators: capabilities (C), motivations (M) and permissions (P). Table 1 shows how these link to the original TIS functions. Similar to a TIS function, it is assumed that an indicators need to be positively fulfilled to constitute a driver for development, when negatively fulfilled they constitute a barrier.

Table 1: TIS functions translated to CE system conditions

TIS Function	Inspired CE condition	Indicators
Entrepreneurial activities	**Mobilisation of human resources**	-New entrants -Incumbent activities

Knowledge development	**Mobilisation (development and diffusion) of knowledge**	-No. Patents -No. R&D projects -Total investment in R&D
Knowledge diffusion through networks	**Mobilisation (development and diffusion) of knowledge**	-No. workshops and conferences on a specific topic.
Guidance of search	**Development of laws and regulations Development of standards and routines**	-No. articles written -Targets set by governments and companies
Market formation	**Formation of markets**	-No. niche markets -Tax regimes for new companies -New environmental standards
Resource mobilization	**Mobilisation of physical resources Mobilisation of financial resources**	-The amount of funds made available for knowledge creation
Creation of legitimacy/ counteract resistance to change	**Development of visions, positive attitudes and expectations**	-Policies with visions and pathway/scenarios -No. Lobby and interest groups

All indicators captured under *capabilities* describe skills and actor that are needed to make the transition towards circular economy. Functions that support capability for CE are: Mobilisation of human resources (as labour and suppliers/subcontractors) (C1), physical resources (C2), and financial resources for innovation (C3); and mobilisation of knowledge development (C4) and diffusion (C5). Following the TIS approach, such resources are essential for inducing experimental CE activities, CE actor network formation, and inducing learning in networks that contributes to developing capabilities which feed system development.

The second category *motivations* refer to actor attitudes and incentives surrounding the actors in the widest sense. Therefore the conditions covered by indicators measure the formation of markets and mobilization of users (M1) along with wider development of positive attitudes and expectations towards CE (M2). Formation of markets can refer to possibilities to tap into different niche markets, actions undertaken by firms or governments to incentivize new user behavior and also describes how the newly emerging markets itself functions in terms of rules, i.e. are they fostered by favorable government taxation or other conditions.

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Additionally, steering positive CE opinions, visions and attitudes is important and feeds back into the forming market and its development, because resistance of users or wider societal concerns with the CE approach might significantly inhibit market formation and other activities employed to attain CE progress.

Indicators that belong to permission describe whether the surrounding system functions in a way as to allow the circular economy (or a particular circular economy innovation) to develop. This refers to conditions established by laws and regulations (P1), and standards and routines (P2). Formal and informal institutions and their rules influence not only the formation of markets but determine the direction of system formation in a wider sense. P1 and P2 conditions refer to the levelling of the playing field in which the actors operate and include implementation guidance by governments and other system actors. Multi-actor and mulit- level policy-making has become common wherein firms and other organisations play a crucial role in bringing about new institutions and policy instruments, and in shaping rule-making and standard setting (Driessen et al).

3.3.2 (Establishing) Progress on the key conditons

One of the key challenges in understanding and recording progress in CE development refers to the long-term nature of societal transitions (ref). Analogue to the TIS framework we start from the notion that there is a formative phase in which the socio-technical innovation system that delivers CE products and services builds up.

In TIS, the formative phase is characterized by high uncertainties as constitutive elements forming the new system are only gradually emerging (Bento 2016.). Especially, the formative phase can see high investments - financial and non-financial - being accompanied by little returns (ref). Old paradigms still dominate and the new system is only gradually replacing mechanisms of the prevailing system and building-up those (functions) which are critical to the new system (ref). It has been suggested by various scholars that these uncertainties are proportionately higher in transitions.

The formative phase can take decades…… time horizons of between 25- 35 years (Loorbach, 2010; Bento…). The construction of new valorization systems of resources involved in a CE transition may even have the character of what Schot et al term ‘deep transitions’ which can take centuries to complete and where the formative phase can be proportionately longer. (In that sense, the formative phase can be viewed as the essential stage where all necessary ingredients are produced and collected for CE and from which several (but not all) eventually come to form a recipe and make growth of the CE possible).

The growth phase is characterized by a strong increase in diffusion of circular innovations in the economy which is most easily observable in higher product sales on a more permanent basis. We suggest to use a 2,5% of the potential market share of CE products as a threshold signaling the beginning of the growth phase, as is also used in TIS analysis (Wilson, Bento, 2016), but other thresholds are also thinkable. Typically such market-take-off affects a number of other system areas, and CE impats accumulate and progress can more easily be traced/deduced by means of using outcome indicators. Furthermore, in the growth phase some of the delayed impacts from activities in the formative phase, for example regarding circularity of product categories with very long lifetimes, have become detectable.

Comparing impacts and effects that characterize the beginning of growth phase with the formative phase, in the latter these are still mediocre/ benign. Progress which is already attained by building up of conditions for wider scale diffusion of CE innovations is concealed and can therefore risk to remain in the dark and go unnoticed in the formative stage of CE development. As x outlines, a key strength in measuring innovation systems with the help of system function lies in their ability to signal successes that can lead to acceleration of progress. Where formative phases take long and progress not readily observed, indicators as introduced in our framework can shed light on the dark phase of CE. Reliance exclusively on outcome indicators can arguably even ave potentially devastating effects for CE development, as it can risk CE losing momentum, leading to withdrawing of investments and thereby eventually to failure of CE as approach for reorganising the human resource production and consumption system.

In order to allow for better representation of progress in the system in the formative phase, we focus on processes and intermediate outcomes rather than final effects in the system. We infer that CE transition processes consists of means (inputs), activities (throughput) and outcomes. We break down the investment into human, financial, material resources (input), and the activities of organisations making use of these inputs (throughput). As a result of the throughputs there are certain results observable which act as intermediate effects in the system (output) and together eventually lead to an effects (outcome) measurable as impact of CE on economy and ecology, e.g. Domestic Msterial Consumption (DCM).

This allows for a vertical and horizontal CE measurement of progress from a process perspective: The vertical four level distinction of progress allows following what means organisations employ in change towards a CE (input), how these means are invested (activities), and the results of these investments (output). Horizontal progress measurement is the progress over time of the CE transition at system level and constituted from the overall results of all measured system elements. Table X provides an overview of all the indicators grouped under the three categories forming the key system conditions over the different vertical progress measures (input, activities, output).
An example of changing conditions related to permissions regards the investment in employees who possess knowledge about legal boundaries and possibilities for legal exceptions for CE initiatives (input) who can arrange multi-stakeholder dialogues and working groups with practitioners and other stakeholders (throughput) for building new policy instruments which entail new standards and rules supporting CE formation (output).

For example, in the Netherlands, Dutch government has specifically invested in employees with CE and legal knowledge to draft a new public procurement tool as an orientation for its suppliers. It distinguishes several basic product categories and within those three levels of circularity ambition. In the tender processes higher scores are awarded to suppliers who can fulfil the highest ambition level (intermediate output, vertical progress). Thereby incentives to use the established standards are lowered and new standards begin to gradually replace these (RWS tool + personal communication Oct. 2018) leading to wider effects in the system (horizontal progress).

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Figure 1: The Circular Economy Monitoring Framework

	Capabilities	Permission	Motivation
Input	Amount of R&D investments in CE No of FTE personnel active in CE research	Number of people working on CE law processes No. of fte in industry associations working on CE	No. of people working on roadmaps / visioning
Actions	No. of innovation projects Share of CE innovation projects / total R&D Network meetings to exchange CE knowledge Subsidies on CE activities Investments in CE activities	Law creation processes Negotiations on new CE supply chain standards	Shared vision meetings Activities to raise CE awareness Consumer awareness campaigns Development of resource taxation schemes Development of public procurement schemes
Output	No. of publications No. of patents No. of new revenue models introduced No. of new CE products introduced Share of CE products / total number of products No. of supply chain innovations adopted	No. of barrier laws removed New CE supply chain standards Laws stimulating CE practices	Total volume of public procurement No. of CE media statements No. of shared vision documents Willingness of firms to engage in CE Level of resource taxation Level of consumer awareness
Outcome /Effect	Prevented material use Emissions, impacts Efficient and effective resource use in the economy		

3.3.3 Integrating CE key notion on resource quality and value

Leaning on innovation systems theory for CE progress can allow for linkage with other concepts critical to CE conceptualization and progress measurement. For example assessment methods such as LCA, MFA or efficiency and performance indicators like RMI/DMC indicators stand in no contradiction to the introduced indicators in the CE progress monitoring framework – rather they are final outcomes of processes observed with indicators in our framework and their widespread uptake can be seen as a marker of a beginning growth phase of CE.

One key element from CE with we directly incorporate in our framework is application of waste hierarchy principle. In order for CE to live up to its accredited potential as a socio-technical transition employing so called R- strategies denoting and steering CE ambitions is essential (see Section X). The waste hierarchy principle of reduce, reuse and recycle is the most widely known and applied in CE (Kirchherr et al., 2018). However, several scholars have proposed more nuanced resource use option strategies. Integrating such a more nuanced distinction of R-strategies into the framework allows getting insights into the types of CE system changes actors induce, their direction and degree.

As can be seen from table X, lower numbered Rs contain shorter physical loops of reverse logistics and applying them more ecological value retained in the system as less new virgin materials have to be employed. They also typically represent options where higher economic value is retained for economic actors, for example a product in repair is typically priced lower than a (new) product going into reuse.

(Absolute) reduction in virgin material use	R0	Refuse	Short loops
	R1	Reduce	
	R2	Reuse	
Extended live expectancy of products and components	R3	Repair	
	R4	Refurbish	Medium loops
	R5	Remanufacture	
	R6	Re-purpose	
Useful application of materials and substances	R7	Recycle	Long
	R8	Recover energy	
	R9	Re-mine	

When applying the framework, recording the R-level for each indicator, thereby serves as additional way to detail progress and the ambition level connected to CE systems. We use a 10-R distinction by Reike et al (with elements from Potting et al), as the authors' formed their taxonomy as a synthesis of the findings in 69 scientific articles presenting the diverging definitions of reuse options operable in various academic disciplines dealing with CE. For feasibility reasons, we suggest measuring according to three main categories of aims: inputs/throughputs/outputs directed at absolute reduction in virgin material use (R0-R2), extended live expectancy of products and components (R3-R6), and useful application of materials and substances (R7-R9). In the next section, we outline other aspects linked to the applicability and use of indicators of the proposed CE progress monitoring framework.

3.3.4 Interconnections among CE conditions

In TIS empirical case studies, it has been established that the functions carry different relevance in different development stages of the innovation system and are strongly interconnected as to affect each other in different ways (Hekkert et al., preferred year?). Essential is the presumption of virtuous feedback loops forming among the key processes for system development in both, the formative and the growth phase. Only as all functions become fulfilled, the system can actually overturn and the new technology replaces the older dominant solution.

The functions constantly interact and as several important functions get sufficiently fulfilled they can initiate positive feedback loops (virtuous) or conversely detrimental (vicious) feedback loops as to halt progress or foster the old system. In past empirical TIS analyses several combinations of virtuous reinforcing functions crystallized as being motors of change, meaning if these are all fulfilled in combination, the entire emerging system gets significantly advanced (ref). In CE literature, recognition of interdependence among different parts of a system and the interconnection of system scales is also presented as central. However, typical patterns in function development and interaction have shown to be valid for describing trajectories of new

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technological systems only and not yet for larger socio-technical transitions.

Various scholars have proposed that transitions are inherently uncertain which makes forecasting the combination of key system conditions takes to move from CE formation to the growth phase very difficult. Simply assuming that CE transitions can be equated with patterns observed in TIS is potentially misleading. We advance that analytical exploration of interactions among the measured motivation, capability and permission indicators could be conducted to reveal possible patterns of positive reinforcement in this forming CE system that can aid the development and practical application/relevance of the proposed framework.

4. Applying the framework: A discussion

Measurement of progress of CE is aimed at analyzing and driving CE in practice. Therefore, it is important to discuss the applicability of the introduced framework in some more depth.

Firstly, all indicators were developed with a view on future CE developments, not only presently observed phenomena. This means that some of them may have a limited applicability in practice to date and were included based on general relevance that is to be observed in the medium-term future. A good example is the indicator 'CE fte's ' . These days, it is difficult to measure CE progress in terms of number of FTEs. First frontrunning companies and government institutions have created FTE positions on CE but most professionals work only a part-time or project base on CE. If CE continues to be relevant to corporate strategy, we expect a similar trajectory for the CE profession as the one of the CSR manager. Whereas about 15 years ago, there were hardly any CSR or sustainability managers in companies there has been a consistent and global development towards larger firms employing full-time sustainability experts (Carbone et al., 2008).

Such a forward-thinking perspective on possible CE developments is also contained in other indicators. For example for different types of plastics labelling has been established and consumer awareness is currently leading to a phasing out of bisphenol-A in many products. Such labelling is however not available for the majority of products and complicates not only informed consumer choice; the problem of 'not knowing what's inside' is just as much an issue for companies that like to engage in closed-loop production and re-marketing processes but are reliable on multiple unlabeled supplies with unknown circularity properties (e.g reusability, resellability longetivity). Including the indicator on CE material passports and CE standards, we point out the need for efforts by large companies, certification organisations, branch organisations, cross-sector associations and government.

Secondly, it is important to keep in mind that the speed and direction of the transition to a CE will differ per substance/ product group / sector/ region and so forth. The indicators present in Figure 1 have been designed to serve as generic measure of CE system progress and are hence most suitable in their current form to measure the progress of the CE system as a whole, i.e. most easily applicable at macro level. Sub- categories have to be derived to establish tailored indicators applicable at different scales including boundaries for data collection appropriate to the measured scale. Progress measured on various scales can also be aggregated to an overall CE progress measure of CE in its formative phase.

Thirdly, the framework contains both qualitative and quantitative data to be measured and monitored. Descriptions are useful in order to get better insight into the degree of change that can be attained through fulfilment of a specific indicator. A further development of the framework could focus on how qualitative data can be translated by means of a scoring system in order to allow for more aggregation of data to assess CE system formation.

In addition, in developing measurement and monitoring systems there is always a trade-off between feasibility and desirability. In design of framework different versions emerged some of which were extremely detailed and included more tailored indicators. The more tailored indicators become, the more complex and resource-intensive measurement tends to become. We acknowledge that the fraemwork is predominantely focused on system formation rather than how the current linear economic system is destabilised. However, we advise to include system destabilsation indicators (for example inspired by Kivimaa & Kern, 2018) and to allow for a "mirroring" of the system-building indicators with system eroding indicators wherever resources allow that this framework is applied for such a comprehensive analysis.

Issues of data availability are also a problem of extensive indicator frameworks. If data on certain indicators in a framework is missing, results are less solid and less meaningful. Our first explorative case studies in the algae sector showed that data on sector level is not possible to obtain. Also for a solid analysis from the perspective of a single entity within a system private data and public data have to be combined. Companies may withhold data for strategic reasons, and certain types of data may simply not yet exist as there has been no large scale, organised data collection by governments other than waste and efficiency metrics improperly reflecting CE formation processes and CE principles. This also renders the applicability of our framework low in practice under current system conditions.

Apart from data availability there are further methodological challenges. For example, when it comes to ambition (R-levels) - quality levels are a policy document or company initiative may address more than one strategy. Further, many system actors such as companies still work with a 3R hierarchy (Kirchherr et al., 2017) and while 5 R hierarchies are increasingly used and more extensive hierarchies designed (Potting et al, 2015) they are not applied everywhere and not applied consistently as there is confusion among the terms (Reike et al, 2018) or there is even intentional misapplication to blur ambitions such as equating CE and efficiency. All of this complicates measurement into the development of global circular economies rather than any 'circularity' Figge et al (2018).

Further, bringing attention to the feedback logic in innovation systems, we acknowledge another possible shortcoming namely that the mere fulfillment of an indicator says little about actual change at system level, both at vertical progress dimension (relation among inputs, throughputs and outcomes) and on the horizontal progress dimension, the moving from one stage of system formation to another. Therefore we acknowledge.

Lastly, it is important to highlight that measuring progress as we seek to do with this framework should not be confused with measuring positive net effects.. For CE in general measuring net benefits is the key challenge as there is a trade-off between physical/thermodynamic limits and economically feasible

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combinations (Korhonen et al,, 2017).

Examining CE progress overall is complicated by a number of factors, and more accurate measurement would ask combining various disciplinary perspectives, share definition of spatial, temporal system boundaries and limits of scholars and finding ways to work with those complexities which seem to be inherent to measuring CE at wider scales including its conceptualisation, boundaries setting.

It is important to note that the framework was designed also with a view on further extension and adaptation. For example, if CE is defined in line with three P principles, the R-model of quality could be combined with sustainability criteria representing the 3 dimensions. Combined indicators in our framework address sustainability 3 dimensions, but single indicators are not necessarily focused on all dimensions. Various scholars have advanced indicators which link all dimensions, and the ability to link various sustainability areas is evident in the trend of integrating sustainability reporting. Hence indicator system could be adapted in line with this for example in examining CE motivations or CE legislation also for their wider sustainability considerations. We encourage further research on framework, applicability, adaptability to different scales and extensions.

The CE Strategist – A learning tool to identify new circular business opportunities and adapt the business model

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Abstract
There is a broad consensus that new business models are a key factor for the transition to a Circular Economy (CE). The paper introduces the methodology of a learning tool, called CE Strategist, which provides guidance for the process of creating a CE-inspired Business Model. Developed within the European Erasmus+ project KATCH_e, the tool aims to help students and businesses alike, to identify circular business opportunities and further define them through an adapted version of the Business Model Canvas (BMC). The tool was being implemented as an openly accessible Webtool. Its methodology follows a four-step process: (1) Description of the current Business Model with a BMC template; (2) Evaluation of value capture opportunities along the whole product life cycle; (3) Selection of the most relevant CE strategies and Evaluation of best-practice examples; (4) Definition of a CE-inspired Business Model with a Business Model Canvas template highlighting potential influences. The innovation of the tool lies in its process design, which not only covers the analysis of CE potentials or the specification of the BM as the majority of existing tool, but provides guidance throughout the whole process of business model design which is the focus of this paper. It discusses, which CE business strategies can be distinguished, how their applicability can be evaluated and how they influence the different elements of a Business Model. The conclusions discuss the inherent limitations of the approach and how these were dealt with.

Keywords: Circular Economy, Circular Business Strategies, Circular Business Models, Business Model Canvas, Tool

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1. Introduction

This paper presents the methodology and the process design of the CE Strategist webtool. It was developed within the european Erasmus+ project KATCH_e, an acronym for "Knowledge Alliance on Product-Service Development towards Circular Economy and Sustainability and Higher Education". The webtool is part of the educational resources developed and is accompanied by a theoretical module on business models. The aim of the webtool is to help the user identify business opportunities of the circular economy and provide guidance along the whole process of business model design. The tool targets product developers and designers from different manufacturing industries, both professionals and students. It is available online under the URL https://tools.katche.eu/.

The CE Strategist is part of a toolkit together with two other tools named CE Designer and CE Analyst. The CE Designer is a semiquantitative Checklist Tool which aims to evaluate the design implications of different circularity strategies in the product and service development. The CE Analyst lets users quantitatively estimate the effects on the product carbon footprint when applying different CE strategies. The CE Strategist is designed on a basic framework that is also usable in all three tools and provide "bridges" and links to the other two webtools. Together the three tools provide a toolkit for CE helping users in design-, business and environmental assessment challenges.

2. Background and Methods

The tool methodology is the result of an extensive literature and practice review of existing tools, frameworks and business case studies. This research was guided by the following requirements the tool should fulfil:

Firstly, as a webtool for an online course, the tool is designed for individual users and not workshop-like settings. Therefore, the goal is to put forward a dynamic process framework throughout the whole business model design process, suitable for individual users, in contrast to merely providing a template for open innovation processes (such as the Business Model Canvas) where often additional "outside" guidance is needed.

Secondly, the tool should provide a useful addition to the concepts and frameworks already introduced in the theoretical module on business models also developed within the project. The use of the tool should be easy to use, provide a learning experience and expose the user to the fundamental idea of a circular economy and the business opportunities it provides.

The business model design process can be structured in three distinct iterative phases (Frankenberger et al. 2013): In the initiation phase the ecosystem is analysed, the needs of the players need to be understood and drivers for change are identified. The ideation phase is about generating new ideas and overcoming the current business logic. Finally, the integration phase is about the "translation" of ideas into the components of a business model.

This process is taken as a blueprint for the methodology, reviewing existing tools and derive requirements for the CE Strategist. An analysis of existing tools with a similar goal of inspiring CE-oriented business model innovation showed that there is a lack of guidance between the individual phases of business model design process - especially from the ideation phase to the integration phase. For example: The two webtools named CE toolkit (Evans and Bocken 2014) and Circular Pathfinder (van Dam et al. 2017) are quite similar in their scope and the target group they address. Both tools were designed as learning tools to quickly assess opportunities of the Circular Economy, from the viewpoint of manufacturers. The tools offer an evaluation of circular economy strategies such as repair, reuse, remanufacturing, products as services, etc. The results are useful to define aims both in terms of an adapted product design or a redefinition of the business model. However, the tools don't differentiate between these two use cases. Both tools focus on the ideation phase, but lack support as far as integrating the generated ideas in a business model.

On the other hand, the Business Model Canvas (Osterwalder and Pigneur 2013), provides a helpful template to organise, analyse and innovate business models by defining nine distinct elements (see Figure 1). Assigning the BMC to the BM design process, it is a useful tool both for the initiation phase and even more for integrating the pieces of a business model.

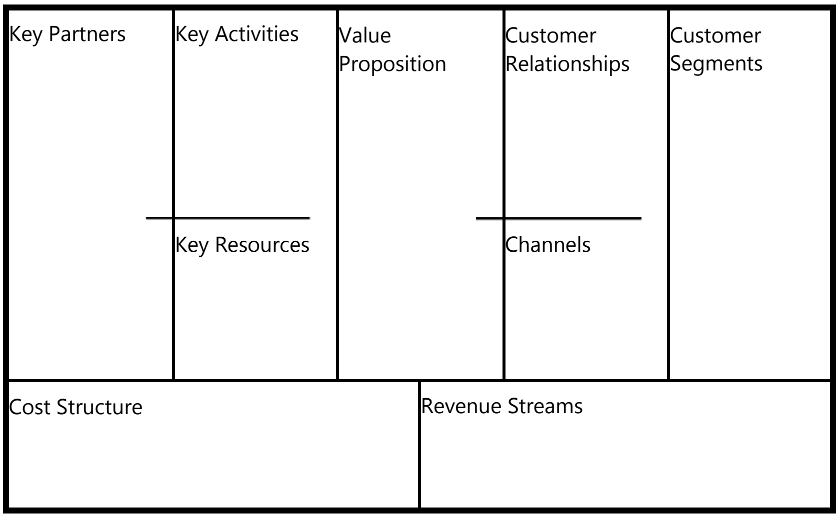

***Figure 1**. The Business Model Canvas (Osterwalder and Pigneur 2013)*

In the sustainable business model innovation literature, there is a broad critique of the "profit-first world view" the BMC implies (Upward 2013). Value to be captured within a business model is mainly conceived as being created for customers only. As a result, critical aspects of sustainable business models such as environmental impacts, finite resources, social considerations or other affected stakeholders than customers are externalised (Upward and Jones 2015). As a consequence, many alternative frameworks for innovating business models sustainably have been introduced in recent years. The method generally has been, adding additional elements, questions or layers to the traditional BMC: The Sustainable Business Model Canvas (www.case-ka.eu) introduces two additional fields below named eco-social costs and eco-social benefits. As the name suggests, the Triple layered Business Model Canvas (Joyce and Paquin 2016) adds two additional layers concerned with social stakeholders and the environmental life cycle on top of the economic BMC framework. The flourishing Business Canvas expands the BMC framework to a total of 16 fields, to integrate social and environmental aspects (Hoveskog et al. 2018).

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However, the appeal of the BMC is quite strong, especially because of its simplicity, resulting in wide spread adoption and name recognition of the concept also outside the business community. Furthermore, many additional elements and layers can also be integrated in the traditional BMC structure, if value is perceived not only in economic terms but also includes environmental and social concerns. As value is at the centre of the definition of the definition of a business model, a “re-definition” of the term has repercussions on all business model elements.

The idea of the CE Strategist is therefore to highlight the opportunities of a CE (similarly to the mentioned Circular Pathfinder and CE toolkit) while translating their implications to the structure of the BMC. Figure 2 shows an overview of the steps the user follows and links them to the business model design process: The user starts by describing the current business model (Step 1), then evaluates which opportunities fit best within the applied context (Step 2), subsequently selects the best fitting strategies (Step 3) and finally defines an (adapted) circular business model with the help of an adapted BMC version which highlights essential influences of the chosen strategies.

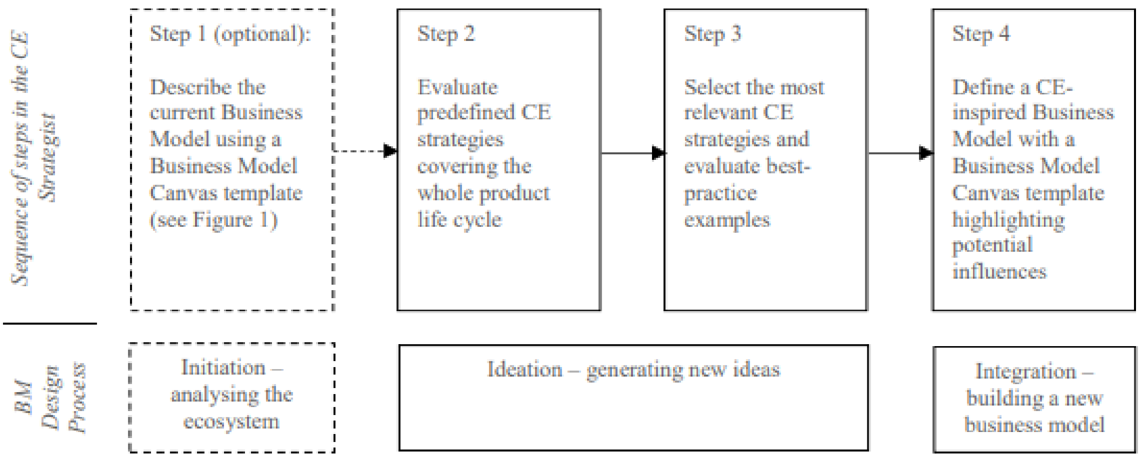

Figure 2. *Structure of the CE Strategist with the corresponding steps of the business model design process according to (Frankenberger et al. 2013)*

The methodological goal of the tool is to link the sustainability-view with the ideal of a circular economy at its centre with the business view of creating a financially viable business model. This goal results in the following research questions, which are covered in the following section:

- Which CE Business strategies can be distinguished?
- How can the potential of the CE business strategies be evaluated?
- How do the CE Business Strategies influence the individual elements of a BM?

3. Results

Which CE Business strategies can be distinguished?

The term circular economy is far from being sharply defined. It means different things to different people and institutions (Kirchherr et al. 2017), which is why a definition for the KATCH_e materials was necessary. There, Circular Economy is defined as a system that is restorative and regenerative by intention and design, which supports ecosystem functioning and human well-being with the aim of accomplishing sustainable development.

The definition builds on the widespread definition by the Ellen MacArthur Foundation (Ellen MacArthur Foundation et al. 2015) and unites it with the concept of sustainable development. By that definition the circular economy can be understood as a model which emphasizes efficient resource flows, but does not exclude other areas of sustainability such as good working conditions. Resource flows can be optimised by narrowing, slowing and closing resource flows (Jørgensen et al. 2018).

In relation to Business Models this also means that Circular Business Models are a subset of Sustainable Business Models (Geissdoerfer et al. 2018). This is reflected in the categorization of Sustainable Business Model Archetypes (Bocken et al. 2014) where examples and archetypes of CE-related business models represent only a fraction of the different variants. To summarize, circular business models are conceptualised as a subtype of sustainable business models which emphasize the efficient use of resources by narrowing, closing and slowing resource flows.

To help in the process of designing a more circular BM, the tool provides a set of predefined CE business strategies. Strategies are understood as a long-term plan of action designed to achieve a goal – in this case with the goal of a circular economy. This is in contrast to business models, which are a concrete and individual manifestation of strategies. This also implies that business models might also build on a number of different strategies.

To enable a more efficient resource use, it is necessary to put the product life cycle in the centre of the idea finding process. The framework of the Value hill communicates this mindset well (Achterberg et al. 2016), and not only highlights opportunities along the life cycle but also shows how the “inner cycles” of a Circular economy provide a potentially higher value capture. By doing so, the framework merges the logic of business strategies with the goal of resource efficiency.

The concept differentiates between business strategies in the pre-use phase (Uphill), where value is continually added, the use phase (Tophill), where value is maintained for as long as possible, and the post-use phase (Downhill), where the value of products, components or materials is retained (Achterberg et al. 2016). This orientation along the product life cycle ensures that the strategies shown provide a complete picture of possible strategy options from the viewpoint of manufacturers.

The CE strategies are also characterised by a change of profit incentives. E.g., use-oriented-services such as pay-per-use systems incentivise the provider to make use of an asset for as long as possible and therefore encourage resource conservation and efficiency by design. This is in contrast to more “linear” business strategies based on product turnover, which often incentivise short product lifetimes and built-in obsolescence.

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Table 1 shows an overview of the eleven CE business strategies used in the CE Strategist. The table also shows how these relate to the frameworks of the Value Hill (Achterberg et al. 2016) and the Sustainable Business Model Archetypes (Bocken et al. 2014). Furthermore, the table highlights how resource flows (Jørgensen et al. 2018) are influenced through the strategy and what potential new profit sources are uncaptured (Moreno et al. 2016).

Table 1. *Overview of CE Business Strategies used in the CE Strategist.*

Value Hill[1]	**Business Strategy**	**Definition**	**Resource Flow[2]**	**SBM Arche-**	**Profit Sources[4]**
Uphill	Circular Sourcing	Using resources as production inputs that are renewable, recoverable, bio-based and/or comparatively resource conservative. (Achterberg et al. 2016) The strategy summarizes innovation approaches which focus on material choices such as Cradle to Cradle, Localisation, Biomimicry, Green Chemistry, etc.	Narrowing Closing	2, 3	a, b
	Maximising Production Efficiency	Describes a number of manufacturing principles that focus both on maximising the material and energy efficiency in the production process, such as Industrial Symbiosis, Low Carbon Manufacturing, Additive Manufacturing, On Demand Production, Dematerialisation, renewable energy, etc. (Bocken et al. 2014)	Narrowing Closing	1, 3	a
	Circular Design	Make use of product design strategies that are actively considering end of use strategies, such as repair, upgradability, modularity, repurposing, closed loop recycling, etc. (Achterberg et al. 2016)	Slowing, Closing	2	c
	Long Life Design	Focusing on delivering long-lasting and energy-efficient products the customers are attached to. Products are often comparatively expensive when acquired. Durability and Sustainability is a major part of the company's communication. (Bocken et al. 2016)	Slowing	6	c
Tophill	Life Extension	Selling consumables, spare parts, and add-ons which support the longevity of products and/or providing repair & maintenance services. (Achterberg et al. 2016)	Slowing	6	d
	Product-oriented Services	Products are sold to consumers with extra services aiming to prolong the use phase of the product. Examples include extended warranties, service contracts, supply of consumables, take-back agreement, consultancy, etc. (Tukker 2004)	Slowing	4	d
	Use-oriented Services	The ownership of the product remains with the service provider. It is made available in a different form and is sometimes shared by a number of users. Examples include: leasing and renting (single user), sharing (sequential use by different users) and pooling (simultaneous use by various users). (Tukker 2004)	Slowing Closing	4	d, e
	Result - oriented Services	Clients and providers agree on a specific result and not necessarily a pre-determined product. All resources used to deliver the result are becoming cost factors for the provider, creating a financial incentive to use them as efficiently as possible. (Tukker 2004)	Slowing Closing	4	d, e
Downhill	Reuse	Providing used products to new customers.	Slowing	2	f
	Remanufacturing / Refurbishment	Restoration of a used product to a condition as good as new. (BS 8001:2017)	Slowing	2	f

	Material Recapture/ Recycling	Recapturing materials and components and/or transforming waste into new materials substituting the use of virgin materials.	Closing	2	a, b

[1](Achterberg et al. 2016)
[2]according to the framework of narrowing, slowing and closing resource flows (Jørgensen et al. 2018)
[3]Sustainable Business Model Archetypes (Bocken et al. 2014): (1) Maximise material and energy efficiency, (2) Create value from waste, (3) Substitute with renewables and natural processes, (4) Deliver functionality rather than ownership, (5) Adopt a stewardship role, (6) Encourage sufficiency, (7) Repurpose for society/ environment, (8) Develop scale up solution
[4]Adapted from (Moreno et al. 2016): (a) from material and energy efficiency, (b) from recovering resources from products/materials, (c) from selling long-life time products or increased functionality, (d) from consumable/ spare part/ service sales, (e) from increasing the utilitzation rate by shared access/ ownerwhip/ performance provision, (f) from providing used/ refurbished/ remanufactured/ upgraded units

How can the potential of the CE business strategies be evaluated?

Having a set of predefined CE business strategies, the next step is about finding out which ones fit best for a specific purpose (see Figure 2). There are a number of methods from existing tools with a similar objective. E.g. the Ecodesign PILOT (Wimmer and Züst 2001) suggests product improvement strategies based on the most relevant life cycle stage from the raw material extraction to the disposal of the product. The already mentioned Circular Pathfinder (van Dam et al., 2017) takes a top-down approach based on the resource hierarchy,

considering the potentials of "inner CE cycles" with a high resource efficiency impact first. The tool starts evaluating options to narrow the resource flow, then looks at options to slow resource flows starting such as long life strategies and finally analyses options to close resource flows. The CE Toolkit (Evans and Bocken 2014) mostly looks at the product characteristics and derives potential improvement measures from there.

The evaluation used for the CE Strategist builds on the analyses of 100+ documented CE practices assigned to the eleven CE strategies, mostly from the construction and furniture sector. The research question was: What are the unifying product and market characteristics that qualify it for a certain strategy?

Relating the question with the framework of the BMC, the analysis looked both at characteristics of the backend (Key Partners, Key Activities and Key Resources) and the frontend (Customer Relationships, Customer Segments, Channels) of successful CE-oriented Business Models. The backend side is associated with the product side of a Business Model, while the frontend customer-facing side of the Business Model on the other hand is also described as the market side (see Figure 1). Similar to the CE toolkit, the evaluation is based on preferable product characteristics (such as material composition, longevity, modularity, production methods, etc.) but additionally looks at supportive market characteristics (such as customer demands, requirements, life time and investment costs, etc.). The result is shown in Table 2, where each strategy was assigned between one and six evaluation criteria. The user is asked to evaluate the accuracy of the statements with a four-point scale of false, mostly false, mostly true and true. The table also shows how the answer influences the evaluation. The (+) means that a positive response influences the applicability of the assigned strategy positively and vice versa.

E.g. if the criterion "customers mainly seek the functionality of a product" is true for the examined product system, it results in a positive feedback for the strategy "result-oriented services".

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The varying number of evaluation criteria per strategy shows that the allocation of explicit and unambiguous criteria for each strategy is challenging. Some strategies allow for more clearly definable characteristics than others. E.g. The strategy "Circular Sourcing" is easily evaluated by analysing the material components of the current product system. On the other hand, finding unifying characteristics which favour the strategy "Product-oriented services" is harder due to the many different types of business models that build on this generic strategy. This resulted in in only one generic criterion.

As the tool targets a wide range of different sectors, some criteria might not be applicable for the analysis of a specific product-system. In that case the tool offers to exclude individual criteria, by choosing not relevant.

Table 2. *Overview of evaluation criteria related to the CE Business Strategies.*

CE Business Strategy	**Influence +/-[1]**	**Evaluation Criteria**
Circular Sourcing	-	Materials are mostly renewable and non-hazardous.
	-	Materials come from local sources, resulting in low transportation emissions.
	-	Materials are sourced under fair working conditions.
	-	A high rate of recyclates is used and the product itself is recyclable.
	-	The materials are highly eco-efficient, having few environmental impacts.
	-	The materials are easily separable. (avoidance of composites and coatings)
Maximising Production Efficiency	+	The manufacturing stage is highly energy and resource intensive.
	+	The production requires significant warehouse capacities.
	+	The energy needed - power and heat - in the production process stems mostly from non-renewable sources.
	+	The production process results in a number of unused waste streams (heat, waste materials, water, etc.).
Circular Design	-	Product parts with a short life time are easily accessible and separable.
	-	Products are easy to disassemble (with standard tools, in a short time, supported by a modularised design).
	-	Product failures are easy to identify and its design anticipates the most likely failures.
	+	Technical Obsolescence (e.g. due to short innovation cycles), if relevant at all, only relates to parts of the product.
Long Life Design	+	Technical product innovation cycles are relatively long.
	-	The product is timeless and/or customizable in its design.
	-	Users are attached to the product (due to its performance, aesthetics, experience, etc.).
	+	The use phase of the product is relevant in terms of its power consumption or use of consumables.
	+	Customers are willing to pay more for a eco-efficient, long-lifetime product.
Life Extension	+	The product is characterised by parts with different lifetimes and/or requires consumables.
	+	The use time of the product is shorter than its potential lifetime.
	+	Reasons for product failures are similar.
Product-oriented Services	+	Customers often hesitate to acquire the product due to uncertainties in its performance.
Use-oriented Services	+	Customers don't need to own the product, but are interested in its functionality
	+	High purchase prices act as barrier for more customers.
	+	The average product use time is shorter than its lifetime.
	+	There is an incentive to take the products back after the use phase.
Result -oriented Services	+	Customers mainly seek a certain functionality, the product is of minor concern (e.g. mobility instead of car ownership)
	+	Products often underperform in their use phase in relation to their potential (e.g. due to limited user expertise)
	+	Products are characterised by high investment (purchase prices) and/or operational costs.

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	+	Customer requirements are highly individual.
Reuse	+	Products are often still functional at the end of their use time.
	+	There is a high customer demand for used products (e.g. due to lower prices).
Remanufacturing / Refurbishment	+	Products are discarded because parts of it are faulty / technologically obsolete / look worn / are out of fashion.
	+	Professional product-specific expertise (such as knowledge, skills, equipment) is needed to reintroduce products into the market.
Material Recapture	+	High material costs are associated with the production of the product.
	+	Large amounts of discarded material are available as potential a secondary source.
[1]*evaluation with a four-point scale between false (-), mostly false, mostly true, true (+); +/- describes the answer which generates a high potential of the corresponding strategy; individual criteria can also be excluded by choosing "not relevant"*		

How do the CE Business Strategies influence the individual elements of a BM?

To achieve the goal of providing guidance in the process of integrating the pieces of business model (see Figure 2, Step 3 to Step 4) the tool is based the following premise: CE business strategies are understood as patterns that produce similar outcomes on the level of the business model. This doesn't mean that every business model, that applies e.g. the strategy "Life Extension" looks the same, but that there are certain elements that are essential to address when following it. For example, applying the Life Extension strategy, will result in recurring Customer Relationships and require the provision of (repair) services as a Key Activity, among others.

This categorisation of essential business model elements that make a circular business model distinctive and unique was put forward by Smith-Gillespie (2017). The CE Strategist builds on these essential elements. New elements were added where necessary based on the business model characteristics of the best-practice examples that also served as the foundation for the evaluation criteria defined for Step 2. Tables 3 and 4 show the essential elements to consider when defining a new business model.

Among others, the tool also shows specific design strategies references as new Key Activities that are fundamental for the business strategy. This not only allows users to recognize a certain design strategy as one of the components of a new business model - for some strategies this relation is more fundamental than for others. In case of the two strategies "Long Life" and "Circular Design", as the name suggests, design is they key idea of its Value Proposition. In others, such as "Maximising Production Efficiency" product design plays a minor role. Still, every strategy necessitates a certain design approach. To evaluate and improve the product design, the CE Strategist links to the CE Designer– see also the contribution about the CE Designer tool in the ERSCP 2019 proceedings. The idea is that the basic evaluation of the applicability of CE strategies can both be used for business model- and product design considerations.

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Table 3. *Essential elements of the CE Business Strategies, adapted from (Smith-Gillespie 2017)*

BMC Elements / **CEBusiness Strategies**	Value Proposition	Customer Relationships	Channels	Customer Segments	Key Activities	Key Resources	Key Partners	Revenue Streams	Cost Structure
Circular Sourcing	SU			NC	D5, D7		CM	WV	MC
Maximising Production Efficiency	SU			VC	D7, D8			WV	MC
Circular Design	LC, SU			NC	D2			PR	
Long Life Design	LC, SU	PA		NC	D1			PR	
Life Extension	LC, SU	RR		NC	D2, SP		CU	SR	LC
Product-oriented Services	LC	RR	RC	NC	D3, SP		CU	BR	LC
Use-oriented Services	LC, AC	LR	RC	NC	D4, SP	UA	CU	PS	LC, FC, TC
Result-oriented Services	LC, PF	LR	RC	NC	D4, SP	UA	CU	PS	LC, FC, TC
Reuse	LC, SU		RC, RS	NC	D1	PA	RL, CU	PR, WV	PI, TC
Remanufacturing / Refurbishment	LC, SU	RR	RC, RS	NC	D7	PA	RL, CU	PR, WV	PI, TC
Material Recapture / Recycling	LC, SU			NC, VC	D5	MR	RL, CU	WV	PI

Table 4. *Explanation of the Essential Elements of CE Business Strategies, adapted from (Smith-Gillespie 2017).*

BM Element	**Essential elements of CE Business Strategies**	
Value Proposition	**LC**	**Lower Lifetime Costs** – through longer uptime of the product, lower operating costs, higher eco-efficiency, providing secondary use cases, etc.
	PF	**Performance** – enhancing the performance by focusing on the desired result (providing light instead of bulbs, mobility instead of selling cars, etc.)
	AC	**Access** – improving through use-oriented service on the product availability, flexibility, range of choices, etc.
	SU	**Sustainability** – providing an environmental or social benefit valued by customers and other stakeholders
Customer Relationship	**PA**	**Product Attachment** – Customers are attached to the product due to its high efficiency, premium branding, etc.
	RR	**Recurring Relationship** – through upgrades, addons, maintenance and repair services, etc.
	LR	**Long-Term Relationship** – through contracts, leasing, services, subscriptions, etc.
	RC	**Return Channel** – offering a method to collect products after the use phase

BM Element	Essential elements of CE Business Strategies		
Channels	**RS**	**Re-Sale Channel** – offering a secondary use channel, often distinct from the primary channel	
Customer Segments	**NC**	**New Customer Segments** – quality-conscious, green, cost-conscious customers	
	VC	**Vertical Customers** - new customer segments outside the current value chain or industry (Industrial Symbiosis, recipients of waste materials, etc.)	
Key Activities	**D1**	**Design of Long-Life Products**	These design strategies can be evaluated with the CE Designer tool
	D2	**Design for Product-Life Extension**	
	D3	**Design of Product-oriented Services**	
	D4	**Design or use-or result-oriented Services**	
	D5	**Design for Recycling**	
	D6	**Design for Remanufacturing**	
	D7	**Design for Material Sustainability**	
	D8	**Design for Energy Sustainability**	
	SP	**Service Provision** – supporting the longevity of products, through support, maintenance, repair, etc.	
Key Resources	**UA**	**Use-Phase Asset Management** – track, manage and service products during the use phase	
	PA	**Post Use-Phase Asset Management** –storing, remanufacturing, refurbishing and reselling products after the use phase	
	MR	**Material Recovery** – Equipment, plants and staff for material recovery processes	
Key Partners	**CM**	**Circular Material Supplier** – Recycling facilities, Waste management, collection systems, reprocessing facilities,	
	RL	**Reverse logistics** – product, component or material recovery provided by a third party	
	CU	**Customer** – becomes a partner by initiating new valuable company processes through takeback, repair, remanufacturing, etc	
Revenue Streams	**PR**	**Product Sale Revenues** – additional or changing product sale revenues	
	BR	**Bundled Product Service Sale Revenues** – from the sale of customer owned bundles with extended warranties, guarantees, takeback agreements, etc.	
	PS	**Product Service Revenues** – from providing access to products while retaining ownership	
	SR	**Service Revenues** – from the provision of services such as selling consumables, maintenance and repair services	
	WV	**Waste as Value** – revenues from waste avoidance	
Cost Structure	**LC**	**Labour Costs** – for providing labour-intensive services	
	MC	**Manufacturing Costs** – due to changing materials, sources, quantities, energy needs, etc.	
	FC	**Financing Costs** – Insurance Costs, leasing costs, upfront investment costs, etc	
	TC	**Logistics and Transport Costs** – service provision, transports, asset tracking, etc.	
	PI	**Product Return Incentive** – Mechanisms such as deposits or credits are enforced to incentivise takeback schemes	

The methodology also allows for the combination of a multitude of strategies. This idea of a mutual dependency of the different strategies is also stressed in the Value Hill framework (Achterberg et al. 2016). E.g., a Business Model that builds on the delivery of a use-oriented service aims to intensify the use of a product due to new profit incentives. This shift of incentives and as products are not changing ownership during the use phase might furthermore encourage downhill strategies, such as “Remanufacturing / Refurbishment”.

In these cases, the BMC template combines the corresponding elements, while excluding duplicates. Figure 3 shows how such a template for Step 4 looks in the tool. The essential elements are shown as editable elements in the tool. Furthermore, items from Step 1- the definition of the current business model – can be imported and of course, new elements can be added. This means that the influences arranged within the BMC-structure are supposed to provide the starting point for the definition of a CE-oriented business model.

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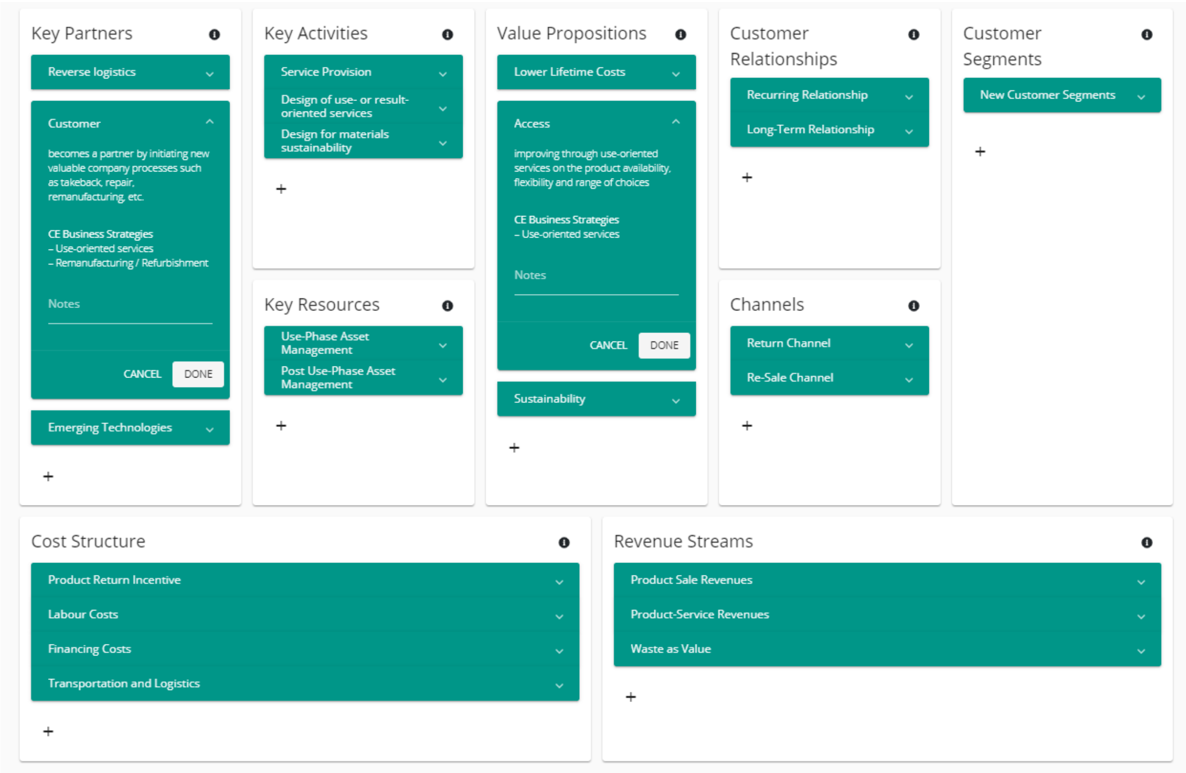

Figure 3*. Screenshot from the CE Strategist with the essential elements related to the strategies Remanufacturing and Use-oriented-Services; Business Model Canvas from (Osterwalder and Pigneur 201*

4. Conclusions

The goal of the CE Strategist tools' methodology is to provide guidance in the process of CE-oriented business model Innovation. As many existing tools only evaluate the CE potentials of a specific product, the main innovation of the CE Strategist lies in the translation of CE potentials from the ideation phase to specific requirements to consider in the integration phase of the business model design process. This approach also results in some limitations regarding the applicability of the tool, which are discussed in this section.

First and foremost, the tools premise of providing guidance, results in the necessity of predefined paths and outcomes. The tool builds on a semi-quantitative evaluation method with predefined strategies, best-practice examples and influences. Therefore, by design, this might result in a narrowing of perceived possibilities. However, this is always a fundamental issue when developing such tools - also supposedly neutral and generically applicable tools such as the BMC are criticized, as discussed in the beginning, for its narrow focus on financial value, resulting in unsustainable business models. The goal for the CE Strategist was therefore to be as transparent as possible about the tools functioning and logic. For one, this is done with the comprehensible evaluation scheme in Step 2, which links each strategy with a number of corresponding questions. Secondly, in Step 4 the tool shows the influences as editable items in the BMC template while also referencing the origin strategy of each item. Both measures assure that the results are comprehensible.

To highlight certain influences on different elements of a business model requires a specific perspective and a number of presumptions. The tool looks at the potentials of a CE from the perspective of manufacturers. This perspective allows to assume a fundamental structure of the Business model. For example, it assumes that the business model builds on revenues from the sale of products or services, it assumes that Product Design is one of the Key Activities, that Key Resources includes physical resources being transformed while Key Partners represent the supply chain. In other words, a certain archetype of the front- and backend of the business model must be presumed in order to highlight influences of a business model redesign. One of the limitations is therefore this narrowing of the target group, which directly results from the aim of covering the whole design process. Still, as the CE represents an idea building on system innovation instead of end of pipe solutions, manufacturers are key to fulfil its promises.

The tool is currently in the process of being tested broadly by different stakeholders (universities and companies) in the four countries of the KATCH_e project partners (Austria, Spain, Portugal and Denmark). Feedback is continuously gathered and the tool is adapted accordingly. Together with the other two webtools developed within the project - the CE Designer and the CE Analyst – the final versions will be available online under the URL tools.katche.eu in December 2019.

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Socio-economic impact assessment in Circular Economy schemes: case study of cork waste management by means of gasification technology

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Abstract

More often than not, methodologies to assess socioeconomic impact are focused on determining just a few indicators instead of impacts, which do not usually cover the whole spectrum of socioeconomic insights. In this sense, the hybrid fulfilment-importance matrix has been developed with the aim to solve these limitations and to calculate the socioeconomic impacts of a new process, service or project. This methodology relies on the holistic approach offered by the LCA, LCC and sLCA methodologies, and is based on a concordance between indicators and impacts, which is quantified. In this way, it allows calculating to which degree objectives have been achieved, and how the impacts and indicators affect the system under evaluation. This fact permits a high degree of transparency and easy reproducibility, coupled with the possibility of hotspot identification. Furthermore, one of the principal strengths is its integrated approach, which permits one to consider the impacts of the process, service or project during different stages of the project. In addition, and based on the life cycle perspective, the hybrid fulfilment-importance matrix permits the benchmarking of the project performance and score against current and baseline situations.

The indicators, displayed in rows, are organized according to technical, environmental, economic, and social indicators. Columns contain the foreseen impacts. These impacts also consider environmental, technical, economic and social insights. For each indicator and impact match, an importance value is given with a value between 0 and 3, based on expert judgement. Furthermore, an achievement factor is adjudicated based on the performance achieved in the project; if the objectives have been fulfilled, a positive factor is applied. If the objectives are not achieved, the value is below zero.

The methodology has been applied within the framework of the LIFE + ECORKWASTE project. The principal aim was to develop a gasification technology capable of obtaining energy from cork gasification, and avoiding cork landfilling. Hence, the above explained matrix has been created with the aim of determining the socioeconomic impacts of the project. In order to achieve this, data provided by technical activities developed during the project was assessed in order to determine the effect on society and specific communities.

The results obtained demonstrate tangible benefits of the technology to society; impacts with special significance include an increase in cork valorisation, the reduction of cork waste dumped in landfills, and an increase in the competitiveness of the cork sector and cork industries. Both technical and economic dimensions are more prominent when indicators are analysed. In conclusion, the socioeconomic benefits of the ECORKWASTE gasification scheme are obtained principally from the reduction of landfill practices,the production of clean energy,

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the re-utilisation of by-products, an improvement of knowledge, and increased investment in human capital. These conclusions underline the main objectives of the project, and allow one to quantify the socioeconomic benefits of the process itself, the potential service to be exploited or project implementation in interested companies. Hence, the hybrid importance-fulfilment matrix has been proven to be capable of assessing from a socio-economic perspective, the LIFE+ ECORKWASTE project in a quantitative and reproducible way.

Keywords: Social Innovation For Sustainable Consumption, Responsible And Collaborative Consumption and Production, Circular Economy, Social Business, Sustainable Management And Operations

1. Introduction

Socio-economics aims to identify, analyse and demonstrate, the potential effect of a planned intervention on the life of residents and/or workers within an identified geographical location where said intervention has taken place. Similar definitions are to be found expressed in distinct manners in numerous studies previously undertaken. Ashford, (2004); Swedberg (1995); Pires et al (2019)

Despite the aforementioned definition being perfectly valid within a broad range of contexts it is not immune to differing interpretations and applications. Hence, when s put into practice, or in other words, when a methodology to determine these effects is to be applied, the nature of the different approaches, the specific aims of each intervention and the geographical context of where a specific action is to be implemented among other factors, results in a lack of consensus concerning said methodology's application. Such drawbacks have been the object of research by a number of authors.

A good example is the work undertaken by Heimlich (2017) who after an extensive review of the related theories, methods and themes, identified four main points for improvement: Socio-economics is clearly lacking a strong institutional platform, thus resulting in a lack of acceptance by physical as opposed to social scientist despite a few isolated endeavours to correct this situation. Secondly, despite efforts addressed to determine important impact in many disciplines and contexts of the approach, it cannot easily be combined to a new unified paradigm or at least, within a unified range of tools that allows one to lay the groundwork of a general theory of socio-economics. And as a consequence of the aforementioned factors, it is clear that a lack of understanding concerning the purpose of this kind of methodology exists. Finally, based on their personal experiences, authors have noted that methodologies to assess a specific socio- economic impact are more often than not, focused on determining just a few indicators instead of concrete impacts, which do not cover the whole spectrum of socioeconomic insights.

This final statement is the result of much research, development and many innovation projects, which have been able to verify (and suffer the consequences of these drawbacks). Thus, it can be stated that there exists the necessity to place in value the knowledge that is generated in this kind of project and the socio-economic impact generated through an approach that permits one to provide a trustworthy method to quantify and calculate the socio-economic aspects of a technology, product, project or corporation at the same time fulfilling the requirements stated in different project programmes. Furthermore, the methodology proposed provides a quantitative and reproducible methodology capable of determining the main socio-economic hotspots The approach provides support to the Circular Economy, as social insights are usually not considered in EU affairs due to the difficulties in providing quantifiable data. By applying what is described here, users can determine the significance of the studied aspects.

2. Methods

The employed method to determine the socio-economic impact is mainly based in the construction of a "socio-economic matrix" based on environmental, technical, economic and social effects. A certain number of indicators have to be selected:

- Technical indicators which determine the degree of achievement of project activities and, demonstrable performance as a whole.
- Environmental indicators based on the application of a Life Cycle Assessment (LCA) study which include the most important environmental categories considered in the study, as well as other aspects not directly evaluated through the LCA
- Economic indicators; based on the Life Cycle Cost (LCC) study which analyse the monitory flows according to expected refunds (if any) and both direct and indirect costs allocated to the technology
- Social indicators; a set of community aspects selected from a social perspective that at the same time, have relevance to the economic development in the region in question

Once defined the indicators taking into account the aforementioned precepts, a significance matrix is constructed in order to determine the relevance of the proposed effects through the socio-economic impact generated. Posterior to that, a semi-quantitative analysis aimed at determining the importance of the selected effects and indicators which produces the final socio-economic matrix reveals the corresponding impact.

The matrix is composed of socio-economic effects in columns, and the considered indicators for the four spheres (technical, environmental, economical, and social) in rows. It permits one to establish what effects and indicators are more connected each other. Once defined, the relative importance of the indicators through a semi-quantitative analysis, it is possible to observe how the project has influenced the different socio-economic effects defined.

Methodology has been applied into the ECORKWASTE LIFE+ project. Its general objective is to create the evidence base for the technical, environmental and economic feasibility of cork waste valorisation, according to their particle size. The innovative strategy modifies the conventional flow – diagram of the cork industry adding among others strategies, a gasification pilot plant capable to reuse cork waste for energetic valorisation with the production of renewable energy. ECORKWASTE minimizes the total amount of waste dumped in landfills, and generates energy from it, improving in this way energy efficiency, and decreasing the environmental impact of cork's industrial activities. Hence, technology converts waste into by-products and, in consequence, enhance the industrial network at a local level, contributing to the diversification of the industrial sector related to cork.

The viability of cork gasification technology for energy production was confirmed from the perspective of syngas quality. A high heating value was suitable for use in cogeneration engines, generating approximately 9,52 kWe and 21,64 kWth, with an average calorific value of 4.943 kJ/m3. The average efficiency of the gasifier was 56.62% for all the cork gasification processes on the pilot plant, with a cork reduction balance higher than 65%. It is expected that in an industrial-scale plant this yield could reach 60%-75%.

Hence, to add value to these prominent results and contribute to project exploitation, the socio-economic

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assessment using the proposed matrix was developed with the help of the proposed methodology, which accounts of four 4 differential steps:

Step 1: Effects selection. Firstly, selected effects are defined as potential socio-economic impacts. The point of these effects is to determine which role the analysed product/project/service plays and how it affects social insight. A panel of experts composed of relevant members of the ECORKWASTE consortia analysed the expected implications of the technology, and selected the following socio-economic impact categories, which represents these effects:

- Skilled jobs increase. The introduction of the ECORKWASTE innovative technology and cork valorisation management process can assist waste management services and public authorities to employ people that would otherwise not be able to work. This, by assisting with keeping or even growing work opportunities within these communities. But also, through the acquisition of these capabilities allowing people to be identified as staff well-trained, able to adapt and knowledgeable in their roles and increase chance to maximize their opportunities in the work market.
- Reduction of cork waste in landfill. The reduction of the amount of cork waste that is landfilled will also bring positive socio-economic impacts. Landfilling not only takes up more and more valuable land space, it also can cause air, water and soil pollution, which can be harmful to human health, as well as to environment. At the same time, it will increase local opportunities and empower industries to diversify their business models.
- Increase of sector competitiveness. In an economic and social perspective, the disposal of waste with energy potential and reusable material content, which could be used for future applications, is a loss of efficiency in environmental and economic terms. Developing a new treatment to valorise or reuse this waste would improve the efficiency of the activity in terms of energy and economics. These savings can contribute to changes in prices and salaries, and in a global increase of the competitiveness of the sector
- Increase of cork valorisation through gasification technology. Along the project the environmental benefits and the positive economic impact of ECORKWASTE technology have been addressed. As a key basis, technology supposed to be economically feasible and expected to bring environmental sustainability. That fact obviously will increase the interest of different interested parties to exploit technology and consequently, the valorisation of this waste flow through the proposed solution.
- Local economy boost. Syngas production through gasification of cork waste has a strong potential for energy recovery, being a net energy-producing process which would produce a high-quality renewable fuel. The expansion of this technology for industrial waste will contribute to the reduction of fuel dependence bringing economic, social and environmental benefit at local, regional and global scales. This decentralized fuel production reduces the reliance on energy imports and increase self- sufficiency of the local communities.
- Competitiveness increase of cork industries. Nowadays the cork industry has to face now to some problems: a high dependence on a single product: cork stoppers for wine, the abandonment of management practices, a decrease in productivity, both in terms of quality and quantity, an ageing population, and some cork oak pests such as "culebrilla" (Coraebus undatus). This creates uncertainty for companies and cork-producing territories. ECORKWASTE proposes an integral and sustainable treatment plan for cork waste which enforces the economy based on valorisation, renewable energy and resources, which could provide the opportunity to increase the benefits of cork forestry management and cork industry while reducing the produced wastes and thus, the environmental impacts related to its disposal, and as a whole, increase the competitiveness.

Step 2: Indicators definition. Different indicators were defined in order to quantify the previously selected effects. These parameters aim to reflect the importance of the defined effects through different aspects of the analysed scenario. A set of 20 indicators in all spheres represented were deployed along them. In the Table 1 are summarized with a clear description about their scope into the. ECORKWASTE project

Table 1. *Indicators considered through the different spheres.*

SPHERE	INDICATOR AND DESCRIPTION
ENVIRONMENTAL	**Climate Change**. Emissions of greenhouse gases to air through technology life cycle in a 100 years' time horizon (GWP100) expressed in kg carbon dioxide/ MWh produced by gasification of waste
	Acidification potential. Atmospheric pollution arising from anthropogenically derived sulphur (S) and nitrogen (N) as NOx or ammonia expressed in kg SO2-eq. / MWh produced by gasification of waste
	Photochemical ozone creation potential. Production of ozone from a VOC emission in terms of kg NOx eq./ MWh produced by gasification of waste
	Freshwater eutrophication. Discharge of nutrients into soil or into freshwater bodies and the subsequent rise in nutrient levels (namely, of phosphorus and nitrogen) in terms of kg P-eq. / MWh produced by gasification of waste
	Cumulative energy demand. Total measure of energy resources necessary for the technology from a life cycle perspective in terms of MJ / MWh produced by gasification of waste
TECHNICAL	**Plant efficiency** in percentage
	Energy consumed. Total energy for the treatment measured in kWh which is consumed per MWh produced by gasification of waste
	Waste reduced. Total amount avoided to be sent to landfill which is valorised for the production of energy per MWh produced by gasification of waste
	Electrical power. Rate at which electrical energy could be released by the plant
	Thermal power. Rate at which thermal energy could be released by the plant
ECONOMIC	**Treatment cost.** Total **c**ost accounting CAPEX, OPEX and externalities trough a life cycle perspective expressed by € / MWh produced by gasification of waste
	Net present value. Difference between the present value of cash inflows and the present value of cash outflows over a period of time in €
	Capital costs. Expenditures of total capital goods required in €
	Benefit / cost ratio. Relationship between the relative benefits and costs of a proposed investment
	Payback period. Time period to recover investment in years
SOCIAL	**Potential local employment.** Jobs to be created in a regional context by the implementation of the project
	Total human population to be affected by the project. Directly workers related to cork harvesting in the region.
	Website visits. Clicks on the ECORKWASTE web page
	Companies implementing green circular economy. Interested companies which have express interest to implement technology
	Implication of NGO. Entities attending and participating in communication and dissemination activities of the project

Step 3: Importance quantification. Different values were given to determine the importance of the defined

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effects. The obtained values feed the matrix representing each element on it. With this structure, the "importance matrix" that defines the significance of the indicators regarding each effect is determined Hence, each matrix element quantifies the relevance of the indicators in relation to the selected effects. To develop it, a semi-quantitative evaluation method was followed. It entails the assignment of a value between 0 and 3 that denotes the importance of the indicator regarding the different impacts according to the details in Table 2. Where there exists no indicator-impact relation, 0 value is given.

Table 2. *Importance determination for each matrix element.*

3	High impact
2	Medium impact
1	Low impact
0	None

As a result, of the three previous steps, the importance matrix is shown in Table 4

Step 4: Achievement determination. Final values are given to determine the achievement of the different indicators and consequently, the socio-economic impact. The resulting matrix permits one to determine to what extent the indicators had been achieved in relation to the objectives proposed at the beginning of the project. Hence, a quantification of these indicators is undertaken. Three columns are added to the importance matrix in which the baseline/initial situation, the planned target to be achieved at the end of the project and, the result finally accomplished can be observed. By direct comparison, the grade of achievement is determined by applying a correction factor respecting the values shown in the importance matrix as indicated in Table 3.

Table 3. *Adjustment factors according to the accomplishment of the goal.*

Level	Accomplishment (%)	Factor
Superior	> 150	2
Excellent	125 – 150	1.5
Average	75 – 125	1
Poor	50 – 75	0.5
Severe	< 50	0

Finally, the achievement matrix is obtained with the mentioned increase/decrease rate of each aspect analysed. Hence, the total score reported is defined by rows which state the socio-economic impact achieved by each indicator, the socio-economic impact accomplished in each category and finally, a total number, which denotes the socio-economic impact finally achieved by the project. In this manner, and by comparing results demonstrated in the importance matrix compared to those derived from the achievement matrix, results could be analysed and final conclusions extracted. The fulfilment matrix is shown in Table 5.

Table 4. *Importance matrix defined*

		SOCIO-ECONOMIC IMPACT CATEGORIES						
	PERFORMANCE INDICATORS	Skilled jobs increase	Reduction of cork waste in landfill	Increase of sector competitiveness	Increase of cork valorisation through gasification technology	Local economy boost	Competitiveness increase of cork industries	SCORE
ENVIRONM.	Climate change	1	2	1	3	1	2	10
	Acidification potential	0	2	1	1	0	1	5
	Photochemical ozone creation potential	0	1	1	1	0	1	4
	Freshwater eutrophication	0	2	1	1	0	1	5
	Cumulative energy demand	0	2	2	3	1	2	10
TECHNICAL	Plant efficiency	2	3	3	3	2	3	16
	Energy consumed	0	2	2	3	1	2	10
	Waste reduced	1	3	3	3	2	3	15
	Electrical power	0	2	2	3	1	2	10
	Thermal power	0	2	2	3	1	2	10
ECONOMICAL	Treatment cost	2	3	2	3	2	3	15
	Net present value	0	1	2	1	1	2	7
	Capital costs	1	1	3	3	2	3	13
	Benefit / cost ratio	1	2	2	2	2	2	11
	Payback period	1	2	3	3	2	2	13
SOCIAL	Potential local employment	3	2	2	2	3	2	14
	Total human population to be affected by the project	1	3	2	2	2	1	11
	Website visits	1	1	1	2	1	1	7
	Companies implementing green circular economy	1	2	2	1	1	1	8
	Implication of NGO	0	1	0	1	0	0	2
	CATEGORY SCORE	15	39	37	44	25	36	196

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Table 5. *Fulfilment matrix obtained*

								SOCIO-ECONOMIC IMPACT CATEGORIES							
	PERFORMANCE INDICATORS	Units	Goal	Result	Expected trend	Acc.	Magnitude	Skilled jobs increase	Reduction of cork waste in landfill	Increase of sector competitiveness	Increase of cork valorisation through gasification technology	Local economy boost	Competitiveness increase of cork industries	SCORE	SCORE PER SPHERES
ENVIRONMENTAL	Climate change	kg CO_2.eq.	186,14	121,80	-	135%	1,5	1,5	3	1,5	4,5	1,5	3	15	
	Acidification potential	kg SO_2-eq.	1,53	0,67	-	156%	2	0	4	2	2	0	2	10	
	Photochemical ozone creation potential	kg NOx eq.	0,53	0,39	-	126%	1,5	0	1,5	1,5	1,5	0	1,5	6	58,5
	Freshwater eutrophication	kg P-eq.	0,08	0,05	-	133%	1,5	0	3	1,5	1,5	0	1,5	7,5	
	Cumulative energy demand	MJ	4604,75	2216,69	-	152%	2	0	4	4	6	2	4	20	
TECHNICAL	Plant efficiency	%	56,00	56,62	+	101%	1	2	3	3	3	2	3	16	
	Energy consumed	kWh	34,76	14,18	-	159%	2	0	4	4	6	2	4	20	
	Waste reduced	kg	-	1540,94	+	-	1	1	3	3	3	2	3	15	71
	Electrical power	kWe	20,00	21,64	+	108%	1	0	2	2	3	1	2	10	
	Thermal power	kWth	10,00	9,52	+	95%	1	0	2	2	3	1	2	10	
ECONOMICAL	Treatment cost	€	76,61	68,58	-	110%	1	2	3	2	3	2	3	15	
	Net present value	€	-	80,315,05	+	-	1	0	1	2	1	1	2	7	
	Capital costs	€	51,16	58,41	-	86%	1	1	1	3	3	2	3	13	59
	Benefit / cost ratio	---	-	2,14	+	-	1	1	2	2	2	2	2	11	
	Payback period	years	-	12,50	-	-	1	1	2	3	3	2	2	13	
SOCIAL	Potential local employment	new jobs	0,00	0,00	+	-	1	3	2	2	2	3	2	14	
	Total human population to be affected by the project	No.	2100,00	2205,00	+	105%	1	1	3	2	2	2	1	11	
	Website visits	No.	1500,00	5922,00	+	395%	2	2	2	2	4	2	2	14	59
	Companies implementing green circular economy	No.	2,00	6,00	+	300%	2	2	4	4	2	2	2	16	
	Implication of NGO	No.	1,00	5,00	+	500%	2	0	2	0	2	0	0	4	
	ECORKWASTE CATEGORY SCORE							17,5	51,5	46,5	57,5	29,5	45	247,5	

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3. Results and Discussion

Results obtained (Table 5) show that from the expected objectives to be accomplished by the project, and represented by the importance matrix, the total score has increased. As can be seen in Table 6, the total score expected in the importance matrix was 196, and the resulting score in the achievement matrix is 247,5. In other words, socio-economic impact achieved exceeded initial expectations.

Table 6. Comparative assessment: importance versus achievement grade of socio-economic impact

Importance Matrix	Achievement Matrix
196	247,5

When each indicator is analysed one can deduce that from the 20 defined, results demonstrated that at least, all of them has achieved the threshold stated. Consequently, from an environmental, technical, economic and social point of view, all objectives pursued were accomplished.

At the same time, when results are analysed from a comparative perspective between the different socio-economic impact categories defined, the results achieved are better than expected in each category. In Figure 1 a spider diagram shows the results in the fourth impact categories at the beginning (expected) and at the end of the project (achieved).

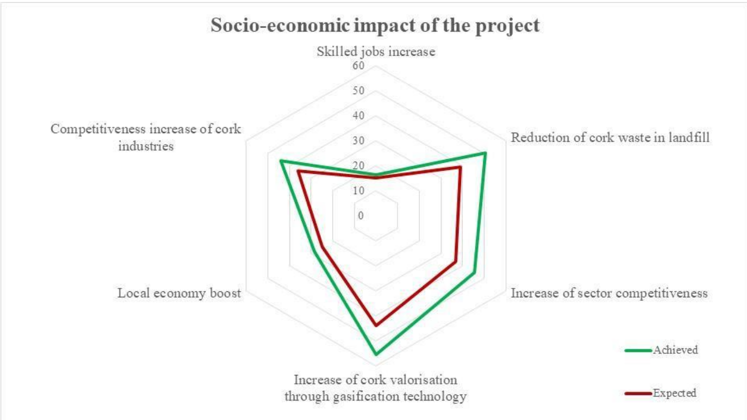

***Figure 1**. Comparative assessment. Socio-economic impact expected and achieved for ECORKWASTE project.*

By analysing each category, can be stated that for the whole socio-economic impact, the impacts with highest influence are the increase of cork valorisation through gasification (57,5 pt) the reduction of cork waste in landfill (51,5 pt), the increase of sector competitiveness (46,5 pt) as well as the competitiveness of work industry (45 pt). All of them have demonstrated a high dependence in terms of importance on technical and economic indicators, and results achieved for these indicators has increased the final values, relation which explain that results.

Rest of categories have accounted a limited contribution respecting to already analysed. Hence, the local economy boost scored 29.5 points mainly based on the economic and social aspects, whereby treatment and total capital costs where emerge the interrelations between the economic profit provided by the technology and the corresponding effects into society. On the other hand, the skilled jobs increase showed the lowest socio-economic contribution. It is due to the lower importance identified in the different aspects, which is especially relevant on the environmental sphere, which only accounts 1.5 point from a unique indicator. In any case, the total score for

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this category was only 15.5 points, where social indictors were the main contributor, that at the same time, does not increase total impact with a significant importance (6 points). To this respect, it is important to underline work held by Bong et al (2017) who proposed the application of awareness strategies, an important part of the project directly linked to the production and use of renewable energy, the main aim of ECORKWASTE. Authors concluded that the collaboration among waste management supply chain and sectors related increasing circularity of the solutions provided, resulting in an increase in human capital and significant contributions to propel the technology. This statement, repeated along ECORKWASTE project, can explain the relevance in results brought by the social sphere.

If is analysed each sphere separately, the same tendency as for the socio-economic impact categories is repeated. When each of them is analysed, for all environmental, economical, technical, and social aspects, ECORKWASTE has demonstrated a value-added performance.

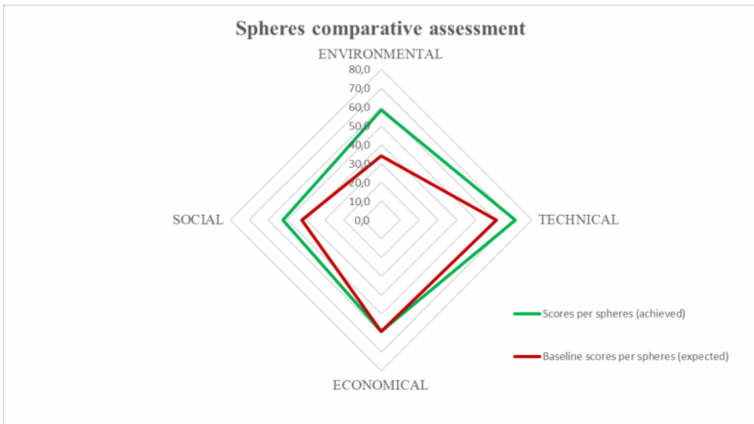

***Figure 2**. Comparative assessment. Spheres defined for ECORKWASTE project.*

Technical aspects are the predominant sphere in the socio-economic matrix. Authors noted that express of importance coming from the consortia and revealed in the importance matrix, denoted the specific status of the technical aspects into the analysis. Not in vain, consortium is composed with a high technical component, where is put into practice an innovative solution by means of a demonstration project. Hence, performance indicators summing 71 points. The plant efficiency was the major player within this area with a total of 16 points, which at the same time is one of the most significant challenges achieved on the project. It is worth to remember that gasifier efficiency was around 57%, with expected reach of around 60%-75% once technology will reach the market. In terms of importance appears once again one of the most important aspects of ECORKWASTE project. The potential waste reduction of the technology (15 points) which have been deployed through a series of measures in an action plan is expected to increase conversion of waste into by-products and, in consequence, enhance the industrial network at a local level, contributing to the diversification of the industrial sector related to cork. This fact surely will reduce landfilled waste.

Regarding the environmental indicators, a score of 58.5 points was achieved, mainly thanks to the energetic outcome in terms of cumulative energy demand. Reduction in this term accounts circa 52% from the expected situation, which is an inescapable aspect consequently highlighted in the results. At the same time, the climate change abatement potential was stated in a 52% reduction from the expected value. That performance is in that sense revealed by a significance on scores achieved in 20 and 15 points, respectively.

The economic impacts scored 59 points, mainly due to the treatment cost indicator (15 points) the most important aspect which has to determine the viability of the technology. A reduction from the initial expected situation was accounted in circa 10%, mainly due to the increase in plan efficiency, which improve results finally obtained, as has been described before. And this in contrast to the capital costs increasing (+14%) that counterbalanced this negative statement.

Finally, the social category depicted 59 points of the whole socio-economic score, mainly based by the potential to create local employment, that at the same time, is the indicator with the higher influence in the majority of socio-economic impact categories (14 points). This fact is aligned with some previous studies, which identify the increasing importance of renewable energies (Bong, Ho et al. 2017, Zabaniotou 2018). This is aligned with current tendencies which will be reinforced with the expected introduction of foreign investors and government incentives. A good example of that is the "Strategy for a bio economy" promoted by the European Commission (2012). As a final deployment of results, for each socio-economic impact category, a comparative analysis between expected (in red as a "Baseline") and achieved in green results is also shown in Figure 3.

***Figure 3**. Interrelation of each indicator in all socio-economic impact categories. Comparative assessment between expected (Baseline, in red) and achieved (green line) situation after project execution.*

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4. Conclusions

Methodology presented have revealed a good response to the main common drawbacks to be fulfilled when socio- economic effects has to be determined. Authors propose a unified approach where technical, environmental, economic and social aspects are analysed with the help of tools like the LCA which among others, allow to determining the main socio-economic hotspots. Thanks to that, it offers a clearly purpose that more often is not well conducted or at least, with a lack of the analysis of determined impact categories, instead the analysis of a set of indicators that in many times are not interrelated.

The hybrid fulfilment matrix provides in that sense a quantitative and reproducible methodology capable to support Circular Economy, as social insights are usually not considered in EU affairs due to the difficulties in providing quantifiable data. By applying what is described here, users can determine the significance of the studied aspects and extract value added conclusions.

An example of that have been described through its implementation along ECORKWASTE project. The obtained results have demonstrated tangible benefits of the technology to society. Impacts with special significance have revealed as the cork valorisation increase, reduction of cork waste dumped in landfill, and the increase of cork sector competitiveness. Both technical and economic dimensions are those with more prominence when indicators have been analysed. In conclusion, the socio-economic benefits of the ECORKWASTE gasification scheme have been demonstrated without a subjective vision of the results achieved, but through a methodology reproducible and based in the work held and demonstrable to assure transparency of results.

The reduction of landfill practices, the production of clean energy, re-utilisation of by-products, improvement of knowledge, and investment in human capital has been in this sense valuated and have supported the accomplishment of general objectives of the project. Furthermore, have allowed to quantify the socio-economic benefits from the process itself and the potential service to be exploited or project implementation in companies interested. Hence, the hybrid importance-fulfilment matrix has been proven to be able to assess from a socio-economic perspective the LIFE+ ECORKWASTE project in a quantitative, measurable and reproducible way.

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The environmental impact of circular products: what do we really know?

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Abstract

The circular economy is billed as a solution to increase economic growth while reducing environmental impact. It is argued that retaining the value of products, components and materials by fostering the "inner loops", such as reuse, refurbishment and remanufacturing, increases the resource efficiency. However, published environmental assessments estimating the actual impact of these so-called circular outcomes are inconclusive. These results can partly be explained by assumptions and differences in methodological choices when conducting life cycle assessments and partly by certain product characteristics. This paper presents the results of a systematic literature review and mapping of previous environmental assessments on circular products. Mapping reveals factors that influence the environmental impact of circular products and other aspects that should be incorporated in environmental assessments. The review as a whole yields impressions of possible weaknesses. First, a lack of studies of products with so-called circular designs that are utilized within circular business models is apparent. While studies assess the benefits of reuse as compared to producing a new product, they almost exclusively assess standard linear products that are offered as part of traditional (not circular) business models. In addition, many assessments are static analyses and limited consideration is given to future increases in the share of renewable energy. One can thus question how well the available environmental assessments quantify actual circular products/offerings and the environmental performance gains they could provide in a circular economy.

Keywords: Circular Economy, Environmental Impact, Sustainability

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1. Introduction

With the growing world population and increasing material consumption, the pressure on the environment is far from being sustainable. Circular economy (CE) is one concept suggesting that it is possible to reduce the pressure on the environment without limiting the economy. This can be achieved by recapturing value present in a product at its end-of-life and recirculate it in the market via e.g. reuse or recycling (EMF, 2013). Not surprisingly, the concept has received a lot of attention in the recent years. China was one of the first countries to utilize the concept in development of state strategies (McDowall et al., 2017) while the European Commission argues that it *"has no choice but to go for the transition to a resource-efficient and ultimately regenerative circular economy"* (EC, 2012) and has adopted a CE package to close product lifecycle loops via reuse and recycled (EC, 2017).

While circular economy as a named concept, field and megatrend is relatively new, it builds on theories from established disciplines, including industrial ecology (Harris, 2004; Chertow, 2007), environmental economics (Ayres, 1998), closed-loop supply chains (Guide and Van Wassenhove, 2001), and cradle-to-cradle design (McDonough and Braungart, 2002). Circular economy is further tangled with other concepts such as the performance economy, blue economy, natural capitalism, regenerative design, and biomimicry (EMF, 2015b). Due to its eclectic nature, it can be argued that circular economy is a bundle of ideas rather than clear concept (Lazarevic et al., 2016). However, at its core, the circular economy refers to the recirculation of goods and materials, i.e. via reuse at product level (for example repair and refurbishment), reuse at component level (such as remanufacturing), and reuse at material level (recycling) (Zink and Geyer, 2017). Thus, while targeting results at the economy or region level, the real change is to be realized at the micro level, with firms and individuals producing, distributing and utilizing products and materials in a more 'resource-effective' way. In theory, there are a great number of strategies to achieving these changes, with new circular product design and performance- based business models making up the core of suggestions for manufacturing firms (EMF, 2013b).

However, whether such strategies can actually deliver the promised results is debated. Scholars increasingly question the link between circular economy and environmental impact (for example Agrawal et al., 2016; Geyer et al., 2015; Murray et al., 2017). A workshop on the potential effects of promoting circular economy via policies concluded that circular economy can have a positive or a negative environmental effect, depending on outcomes on the micro level (Lucas et al., 2016). Indeed, the impacts of CE strategies are promising but mixed and scantly investigated. Some researchers have argued that certain components of a circular economy, such as product- service-systems (Agrawal and Bellos, 2016; Mont, 2004; Tukker, 2005), reuse (Cooper and Gutowski, 2015), and remanufacturing (Gutowski et al., 2011; Peters, 2016) are not panaceas for environmental sustainability. The environmental performance of circular business models is unclear and the available literature is scant (Bocken et al., 2016).

Based on the limitations of current knowledge on the links of CE strategies to environment impact outcomes, there is a clear need for research to learn about the environmental impact of circular products and circular business models and how to compare them against the traditional linear offerings. With this need in mind, we pose the following questions: (1) what do we know about the environmental performance of circular products compared to linear ones? (2) what characteristics are determinants? (3) what does this mean for future life cycle assessments (LCA) of circular products?

This paper conducts a systematic review of studies assessing the environmental impact of so-called circular products and circular business models. Key factors that impact upon the environmentally-preferred strategy are identified. We notice that many environmental assessments of so-called circular products are actually products performing in states of design and systems that are geared towards linearity (e.g. sales model and conventional product design). We reflect on the limitations of the LCA assessments and provide suggestion for future research.

2. Methods

In order to map the current knowledge and evidence on the environmental performance of circular products and business models, a systematic literature review was conducted, focusing on studies that investigate the impacts of 'slowing resource cycles'. 'Slowing resource cycles' extend the utilization period of products via for example direct reuse or remanufacturing and reuse rather than closing them via recycling (Bocken et al., 2016b) as larger environmental impact gains are to be expected from so-called tighter loops. While processes like remanufacturing may alter the product in some manner, it keeps the product intact meaning it requires fewer changes to recover value as opposed to recycling, which involves breaking the product down to the material or substance level and starting over. Hence, as general rule, remanufacturing results in higher environmental savings than recycling (EMF, 2013b). Considering this differentiation, we exclude studies on recycling and focus instead on papers that quantify the environmental impact of so-called circular products and solutions, those that aim to achieve reuse of the product or its components via remanufacturing. As such, we designed our search to find those type of papers.

Papers were searched in early 2018 using Scopus. Keywords included circular economy, circular products, circular business models, closed-loop supply chains, remanufacturing, refurbishment, reuse, upgradeability, and product life extension in combination with environmental impact, LCA, or environmental performance. After removing the duplicates and reviewing the title, 239 articles were identified. Of these, 40 papers actually quantify the environmental impact of one or several circular products, resulting in 72 cases. The cases were classified based on product type studied, noted product design strategies and business models for circular economy, and their results were summarized. Together, the papers and their descriptions represented a collection of analyses of products that have circular tendencies. This collection provided two main insights; (1) indications of how circular products might fare environmentally and what characteristics of the product systems are important to environmental performance outcome and (2) insights into how analyses are done. From the assessment of the analyses, we generate lessons learned related to methods and approaches to assessing environmental impact of circular products.

3. Literature review

The papers provide a collection of analyses of products that undergo so-called circular processes or have circular intentions (see Table 1). This collection gives us indications of the potential environmental sustainability of 'circular' products. We summarize this collection in three sections considering what circular strategy (design or business model) is observed for the circular outcomes analyzed; (1) products that exist with a design and business model that is not modified - it is made for a linear product (no circular strategy), (2)

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products that have a design that is 'intended' for circular use (circular product design) and (3) products that are offered within an alternative circular business model.

[table 1 somewhere here]

3.1. Summary of papers looking at recirculating but without changing products design or business model

A few papers calculate the environmental impact of reusing products (direct reuse) compared to manufacturing them new. For example, Woolridge et al. (2006) assess the benefits of cotton and polyester clothing reuse by calculating the energy use of Salvation Army operations in the UK. Perhaps unsurprisingly, they conclude that the total energy use of collection, sorting, baling, selling and distribution of the used clothing is a fraction of the energy required to manufacture them from primary materials. Low et al. (2016) calculate the environmental impact of reusing flat-panel display monitors via second-hand sales and conclude that reuse leads to less material and resource used in the production process leading to environmental benefits. However, the use phase is out of scope, which is notable for a product that uses energy during use.

More papers explore the environmental impact of recirculating products via refurbishment or remanufacturing and compare the impacts of such process against the impacts of producing new counterparts. Benton et al. (2017) (diesel generator set) and Gao et al. (2017) (turbocharger) conclude that remanufacturing recovers most of the embodied energy and therefore leads to significant environmental benefits. Similarly, Afrinaldi et al. (2017) and Liu et al. (2016) demonstrate significant energy savings when remanufacturing a cylinder block due to the reuse of materials compared to using raw materials in the production of new engines. Van Loon and Van Wassenhove (2017) assume that a remanufactured chassis product replaces a new one and found that remanufacturing results in a reduction in CO_2 emissions. Smith and Keoleain (2004) similarly conclude a large reduction in environmental impact from remanufacturing engines. However, the study ignores the use (and disposal phase) which essentially means that the results are representative only if the efficiency of a new engine is the same as the refurbished one. Kwak and Kim (2016) further showed that remanufacturing alternators saves between 70 and 35% (depending on the remanufacturing yield rate) of the greenhouse gas emissions associated with new production. Finally, Warsen et al. (2011) assessed life cycle impacts of remanufactured versus new manual auto transmissions and find 30- 45% reductions for all categories.

In general, it can be argued that the remanufacturing process yields benefits in terms of resource efficiency compared to the manufacturing process (Allwood et al., 2011; Sundin, 2004; Ijomah et al., 2007), but one can question the benefits if the remanufacturing processes allow less efficient, energy-demanding units to be economically repaired and renewed, hence allowing them to live longer and resulting in more environmental impact than if they had been replaced with new ones or by none at all (Linder et al., 2018). Several researchers looked into the question whether it would be better to keep using a product or to switch to newer models with improved efficiency in the use phase. Gutowski et al. (2011) assessed the energy savings reached through remanufacturing of 25 different product types. Resulting energy savings from remanufacturing (assuming it allows an equally long second life) was a mixed bag (with 8 cases that saved energy, 6 did not, and 11 to close to call). They concluded that remanufacturing generally results in life cycle energy savings for products that do not require energy during use (or require very little). However, remanufacturing generally does not result in energy savings for products that have a large energy requirement in the use phase and for which the energy-efficiency is increasing significantly for newer generations. Similarly, Iraldo et al. (2017) presents LCA results from three types of energy-intensive equipment; refrigerators, freezers, and electric ovens. When considering energy- consuming products, the savings in material and production by extending the product life are weighed against the use of an older and in many cases less energy-efficient product than the savings of acquiring a new, more efficient product earlier. They illustrated that durable products mainly save on environmental impact categories associated with the manufacturing phase, e.g. human toxicity, freshwater ecotoxicity, and resource depletion. On the other hand, environmental impact categories related to energy consumption during the use phase show a larger environmental impact for extended product life. For some product cases, life cycle climate change reductions can be achieved when new replacement products are only minutely more energy-efficient than their older counterparts. They note that small efficiency improvements (5-20%) in the use phase are enough to justify replacement environmentally.

When the use phase is included in the environmental assessment in order to include energy-efficiency improvements or product deterioration over time, the environmental benefit of remanufacturing some products becomes less positive. For example, De Kleine et al. (2011) and Kim et al. (2006) argue that deterioration in operating efficiency, like that seen when residential air conditioners or refrigerators become older and less energy- efficient, significantly reduces the optimal lifetime of the product and hence should be included in the environmental assessment.

Some consideration has been made to what product characteristics determine the most environmentally friendly strategy, extend or replace with new. Iraldo et al (2017) and also Ardente and Mathieux (2014) concluded that the most environmentally friendly strategy depends mainly on a few factors:

1) the lifetime of the products,
2) energy consumption of the product,
3) impacts due to lifetime extension, and
4) efficiency of the replacement product.

For example, extending the product life of smartphones is beneficial from an environmental point of view since a large share of the impacts are generated in the manufacturing stage. On the other hand, washing machines are a type of product that might be better replaced due to the increased energy-efficiency in the new product (Kwak, 2016). Similarly, Intlekofer et al. (2010) assessed replacement scenarios for computers and household appliances and recommended longer lives (than the normal 4 years) for computers (manufacturing is a large part of the total environmental impacts), but on the other hand shorter lives for washers and dishwashers (with a relatively high energy use in the use phase). Tasaki et al. (2013) conducted a relatively similar assessment on refrigerators, TVs, and air conditioners and concluded that lifetime extension is mainly beneficial for products that have a comparably higher environmental impact in the manufacturing stage than the use phase. Cheung et al. (2018) argues that LCD projectors should only be remanufactured if newer models are not significantly more energy-efficient. Bakker et al. (2014), on the other hand, concluded that the optimal lifetime for today's refrigerators and laptops in regards to environmental impacts are significantly longer than their average lifetimes.

Another factor that impact the optimal lifespan from an environmental point of view is consumer behavior, i.e. usage intensity of the product (Tasaki et al., 2013). Perez-Belis et al (2017) argued that the environmental impact depends on consumer behavior which makes it impossible to define one optimal strategy that holds in all situations. Bobba et al. (2016) showed in their LCA on vacuum cleaners that extending the product life of

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vacuum cleaners will in almost all cases lead to environmental benefits, unless the new replacement vacuum cleaner is 25% more energy-efficient.

It is important to note that these conclusions are greatly dependent on the type of energy source used, a point that is conspicuously absent – not even mentioned in many of these studies. Iraldo et al. (2017) notes electricity mix being an important parameter in their literature review, though no electricity mix is explicitly stated (electricity is only discussed in regards to price), and the sensitivity related to this parameter is not discussed (even though energy-efficiency and other factors are assessed thoroughly). While the burdens resulting from extending the life of energy intensive products via remanufacturing is amplified if the product is used in fossil-based systems (internal combustion engine vehicles) or fossil-heavy regions, these burdens can become negligible if the product is to be used in fossil-free (low-carbon) systems or regions. Most studies do not specify the exact energy mix used in their LCA and provide no sensitivity analysis on the impact of the chosen energy mix on their results (see table1) making it difficult to explore the impact of changing energy mixes on this conclusion.

Another key point that deserves further discussion is the assumption about reused products replacing new ones and not merely adding available units to the pool/stock. The studies above usually assume that a reused or remanufactured product substitutes a newly manufactured product. A more nuanced view is taken in operation research literature, where the impact of remanufacturing on the overall demand and consumption of products is included in the environmental assessments. Remanufacturing drives down the prices of the product, which increases sales (Raz et al., 2017). This leads to an overall higher energy consumption, since the impact of increased consumption is higher than the savings from substituting some new products with remanufactured products (Raz et al., 2017; Xiong et al. 2016). Due to the higher overall demand the absolute environmental performance of a system with and without remanufacturing are less clear, even if the environmental impact of remanufacturing a unit of product is significantly lower than producing a new unit (e.g. Esenduran et al., 2016; Shi et al., 2016). It is likely that remanufacturing items with a relatively high environmental impact during the use phase leads to higher system wide environmental impacts due to the higher supply/demand (Esenduran et al., 2016; Liu et al., 2017). However, emissions per revenue generated might be a better proxy for environmental impact and remanufacturing scores better on this ratio than manufacturing only new items (Shi et al., 2016).

3.2. Summary of papers looking at recirculating coupled with a new (circular) product design

Few environmental studies include possible (circular) design changes in their assessment. A good circular product design from an energy use point of view depends on the product characteristics: if the product is subject to no or very small energy-efficiency improvements, designers might want to focus on durability of the product, while on the other hand, designers might want to prioritize modularity and upgradeability of energy consuming parts if large energy-efficiency improvements are to be expected (Cooper and Gutowski, 2015). Kerr and Ryan (2001) assessed the environmental impact of remanufacturing a photocopier compared to producing a new one. They found that a copy machine with a modular design can reduce the environmental impact further than a non-modular conventional design, although in both cases remanufacturing leads to significant environmental savings. Their study is however indicative and focuses only on the impacts of the manufacturing / remanufacturing process itself. Kwak and Kim (2016) assessed the remanufacturing of desktop PCs assuming that some parts need to be replaced in the remanufacturing process due to obsolescence including changing customer preferences. They showed that while the remanufacturing process requires significantly less greenhouse gas emissions than manufacturing new desktop PCs, this advantage can be completely offset by the usage impacts if a significant amount of energy- efficiency increase was realized between the two models. Taking into account the average lifespan of desktop PCs and the energy-efficiency improvements over time, the authors argue that remanufacturing is not beneficial. However, they also argue that product design can be optimized to improve the benefits of remanufacturing and that further research towards product design and the value of remanufacturing is needed (Kwak and Kim, 2016). Similarly, Sabbaghi and Behdad (2017) argue that the environmental impact of remanufacturing versus manufacturing new computers heavily depend on the repairability and reusability of the product.

Krystofik et al. (2017) assessed the environmental impact of remanufacturing office furniture – a no energy consuming product susceptible to fashion changes, making the products obsolete if they cannot be upgraded during the remanufacturing process. The authors argue that design for upgradability allow the product to meet current demand and hence results in a much longer lifespan reducing the environmental impacts per use.

3.3 Summary of papers looking at recirculating coupled with a new (circular) business model

Few studies empirically investigate the environmental performance of servicized or product-service systems (PSS) as compared to traditional ownership models. A servicized business model is one in which the ownership of the product remains with the company in combination with a pay-per-use pricing structure (Agrawal and Bellos, 2016). Tornese et al. (2018) assess the impacts of reusing pallets in a pooling system compared to using pallets only once. They found that the CO_2 emissions of repair is only a fraction of the emissions of manufacturing new pallets and the overall environmental impact depends largely on the handling/loading conditions of the pallets and transportation distances.

It is argued that PSS would stimulate the original equipment manufacturer (OEM) to reduce their production volume and therefore contribute to resource efficiency. Because customers pay depending on the usage of the product, it is anticipated that consumers will use the product less frequent. On the other hand, people with low usage intensity might be more inclined to use the product if they can pay for only their use and not have to buy the product (Agrawal and Bellos, 2016). These changes in customer behavior contribute to rebound effects and should be included in environmental assessments to capture the full environmental effects of shifting to circular business models (Dal Lago et al., 2017). The new offer might also substitute other products than the initial product and finding data on this substitution and rebound effect is challenging, especially in the early design phase (Kjaer et al., 2016). Demand for a product depends on the pricing of the product and hence pricing decisions and subsequent demand should be included in environmental calculations (Agrawal and Bellos, 2016). To complicate things further, the scant research available has shown that the reliability and energy-efficiency of the product might change when companies shift from a linear to a circular business model (Agrawal and Bellos, 2016; 2016b).

In principle, PSS shift the focus from product to the function it provides or its availability, which means that the environmental impact should be calculated over the function delivered (including related environmental impacts of required products and activities to deliver the function) instead of calculating the environmental impact over one product. It is argued that the selection of the functional unit in a PSS is therefore an arbitrary process (Dal Lago et al., 2017). While PSS is a relative new concept, selecting the right functional unit is a key concept in LCA practice and is presented in even early LCA handbooks. For example, functional units as

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'watching TV for one hour' (Guinee et al., 2002, Part 3 p 78), '1000 hours of light' (Guinee et al., 2002, Part 3 p 82), or '20 m2 of wall covering with a thermal resistance of 2 m2 K/W, with a colored surface of 98% opacity, not requiring any other painting for 5 years' (Guinee et al., 2002, Part 2a p22) are described, referring clearly to the function or performance instead of the product.

4. Analysis and discussion

The collection of studies gives us insights not only into products and the potential of circular products in regards to reducing (relative) environmental impact, they also give us insights into the common methods and norms followed when conducting LCA of products.
reducing the impacts from these activities. Energy-efficiency improvements can be incorporated in the 'old' product by replacing the energy- consuming components during remanufacturing via design for upgradability and modularity. However, as pointed.

4.1. Key factors for determining environmental impact of circular products

Based on the assessments of circular products collected (and listed in section 3), several product or industry characteristics can be identified that seem to have a determining role in whether a product will be suitable for a circular economy, meaning that recirculating such product will reduce the environmental impact compared to producing only new products.

- Extending product life: A first prerequisite to reduce a product's environmental impact is the ability to extend product life via reuse and/or remanufacturing. Extending the life of products can result in greatly reduced environmental impacts; more overall function is achieved while the impacts from material extraction and manufacturing stay – depending on what components have to be replaced to achieve reuse close to the same. As a general rule, it is beneficial to extend the life of products that have a relatively high share of total environmental impacts in the manufacturing phase while, it is not beneficial to extend the life of products that have a relatively high share of environmental impacts in the use phase, that is, if new products exhibit better use-phase energy-efficiency.

- Efficiency and environmental burdens during use: Some products deteriorate over time, leading to higher energy or resource consumption than when the product just came on the market. If the deterioration is relatively large, the product can perhaps better be replaced instead of being used rather inefficiently. Similarly, if new products have become more energy-efficient due to new innovative technologies, it will be better to replace the product instead of extending the use of inefficient old technologies. The exact moment of replacement that leads to the lowest environmental impact depends on the electricity mix and usage intensity. Heavy used energy-consuming products have a relative larger share of the environmental impacts in the use phase. It might therefore be better for a heavy user to switch to a newer model while low-intensity users might be better off by keeping their current product.

- Point of obsolescence: When exactly the product is replaced does not only depend on the technical lifespan of the product (i.e. how long the product functions), it is for a large part also determined by the user. Customers might decide to no longer use the product for different reasons; aesthetical, economical, functional, technological, or social reasons (Burns, 2010). When the customer perceives the product as obsolete, the product may be discarded. Products in innovative markets might be discarded far before its technical lifespan is reached and efforts to extend the technical lifespan are meaningless if the product is not used that long.

As widely argued, a manufacturing company can invest in designing their products/business in such way that some of the above-mentioned impacts are minimized. Product design can influence the lifespan of the product, the maintenance and repair activities needed during the use phase, energy and other resource consumption in the use phase, and the recirculation possibilities (e.g. recycling) after use. Product design can also help to keep products relevant longer by allowing upgrades that will mitigate obsolescence (Cooper, 2010). For example, designing products with product life extension in mind including the necessary activities that need to be performed to reach that (such as design for disassembly and remanufacturing), might help in out above, the environmental impacts of design for upgradability and modularity are ambiguous as these design strategies might also lead to additional demand from customers.

In a similar vein, business models may influence how products are used. For example, OEMs may incentivize product return leading to to high return and reuse rates but also changing user behavior in unforeseen ways. However, that does not necessarily mean that the alternative to the OEM-controlled model results in only one use of the product. Independent remanufacturers and second-hand markets can also lead to high reuse-rates. Business models might further influence the usage duration depending on if people have purchased the product, are leasing the product, or are paying on a pay-per-use basis. Knowing what will happen with the product and how it will be used after putting it on the market can be very difficult. More research will be needed in order to be able to conduct quantitative environmental assessments of various circular business models.

4.2 Environmental impact assessments methods

While there are numerous environmental impact assessment methods, LCA is largely considered as the leading tool to assess the environmental impact of circular products (Haupt and Zschokke, 2017). However, when applying LCA to circular products, a couple of potential issues arise (Elia et al., 2017).

Peters (2016) argues that a long-term consequential LCA that looks at the environmental effects of remanufacturing systems (i.e. expanding system boundaries to calculate the environmental effect of a system where products are manufactured and remanufactured including remanufacturing yield rates etc. and compare them against a system where all products are manufactured new) is the most appropriate, realistic and accurate view. Unfortunately, due to data limitations, most LCA studies only compare a single new product with a successfully remanufactured product. Therefore, they only compare the direct impacts of the manufacturing and remanufacturing processes, but do not include the wider system impacts from products that cannot be successfully remanufactured.

Rebound effects, although mentioned in several papers, are so far not addressed and incorporated in the environmental assessments identified in this paper. It is argued, however, that even if circular economy would be implemented to its fullest extent, the rebound effects will lead to an overall growing use of materials and increasing our impact on the environment (Korhonen et al., 2018). For example, the availability of (cheaper)

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used products may merely increase consumption by allowing consumers to afford and own more products (Zink and Geyer, 2017). The question therefore becomes: *Does the availability of used products actually replace manufacturing of new products?* Several ways to include rebound effects in environmental assessments are suggested. Thomas (2011) suggests parameterizing individual's buying habits and proposes a set of equations which are to be an economics-based foundation for assessing to which degree buying used products replaces buying new in a given market. Farrant et al. (2010) takes a different approach and translates consumer behavior

– as described via a survey – into levels of replacement of new production. They assume that purchases made by people that usually or always buy clothes at second-hand markets replace new production, whereas those purchases made by those who do it seldom, looking for "unnecessary" extra things, replace less new production (per purchase) as they are considered superfluous. However, one could consider that the mere availability of second-hand clothes that are cheaper increases purchasing power. Moreover, the presence of a second-hand market may increase the incentive of people to replace their "used" clothes with new ones, knowing that they can get some of their investment back and that the clothes will be used by someone else anyway (reducing moral burden). Research on the various customer segments and their sizes is in its infancy (Abbey et al., 2015). These types of outcomes demonstrate a limitation in especially assessments of relative environmental impact. This suggests a need to consider changes in consumption patterns and how it affects *absolute* system wide environmental impact.

Finally, it has been suggested that it is important to consider larger (societal/macro) changes towards CE when modelling the environmental impact of circular products on micro level, which includes the shift to electricity production with lower carbon intensity (Haupt and Zschokke, 2017). Most notably, while renewable energy is one cornerstone of the CE vision (EMF, 2013), most studies gathered do not explicitly assess electricity mix nor do they consider what effects changing to renewable energy sources would have. Assessing a product's true long- term compatibility with CE should consider not only the current state of fossil-based energy system – in which one may be incentivized to innovate on short cycles and build short-lived products in order to gain 'energy- efficiency'— but future energy states as well.

5. Conclusions

While the remanufacturing process itself, compared to manufacturing new items, results in many cases in lower environmental impact, these studies provide only one piece to the puzzle regarding the question whether CE will improve resource efficiency. Broader impacts, from e.g. return transports and not reusable items, energy-efficiency improvements and degradation, and rebound effects complicate the answer. It is remarkable that, despite circular product design and circular business models strategies being central concepts within CE, there appear to be limited studies focusing on assessing their environmental performance. Similarly, larger societal CE changes, like switching to renewable energy, are not often incorporated into the environmental assessments of circular products. We are left "without proof". Future research should include, or at least reflect, on these aspects to provide a coherent answer on the question whether circular products are indeed environmentally preferred to linear products or as importantly, how to make sure they will be.

Table 1: Overview of papers calculating the environmental impact of circular products (↘ lower environmental impacts when remanufacturing / reusing / extending life than producing new product, → uncertain outcome depends on conditions, ↗ remanufacturing / reusing / extending life lead to higher environmental impact than producing new product)

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Paper	**Product**	**Circular Economy perspective**	**Result**	**Circular product design**	**Circular business model**	**Rebound effects**	**Energy mix and other long- term CE changes**
Woolridge et al. (2006)	Clothing	Reuse	↘				
Low et al. (2016)	flat-panel display monitor	Reuse	↘				
Benton et al. (2017)	Diesel generator set	Remanufacturing	↘				
Gao et al. (2017)	Turbocharger	Remanufacturing	↘				
Afrinaldi et al. (2017)	Cylinder block	Remanufacturing	↘				
Liu et al. (2016)	Cylinder head	Remanufacturing	↘				
Van Loon and Van Wassenhove (2018)	Chassis products	Remanufacturing	↘				
Smith and Keoleian (2004)	Car engines	Remanufacturing	↘				
Kwak and Kim (2016)	Alternator	Remanufacturing	↘				
Warsen et al. (2011)	Transmission	Remanufacturing	↘				
Peters (2016)	Paper folding machine	Remanufacturing	↘				
Diener and Tillman (2015)	Bearing (industrial use)	Remanufacturing	↘				
Biswas and Rosano (2011)	Compressor	Remanufacturing	↘				
Goldey et al. (2010)	Telecommunication equipment	Remanufacturing	↘				
Du et al. (2012)	Machine tools	Remanufacturing	↘				
Gutowski et al. (2011)	Furniture (desk, chair)	Reuse	↘				
Gutowski et al. (2011)	Textile (t-shirt, blouse)	Reuse	↘				
Gutowski et al. (2011)	Appliances (dishwasher, refrigerator, washing machine)	Remanufacturing	↗				
Gutowski et al. (2011)	Truck tire (3 times)	Retread	→				
Gutowski et al. (2011)	Computers (desktop control unit, 2 laptops, 3 monitors)	Reuse	→				
Gutowski et al. (2011)	Toner cartridge	Refill	↘				
Gutowski et al. (2011)	Electric motors (6 times)	Rewind	→				
Gutowski et al. (2011)	Engines (2 times)	Remanufacturing	→				
Wang et al. (2017)	Video game consoles	Remanufacturing	→				
Latham (2016)	Vehicle	Remanufacturing	→				
Kim et al. (2003)	Automobile	Lifetime extension	→				
Iraldo et al. (2017)	Refrigerator/freezer	Lifetime extension	↗				
Iraldo et al. (2017)	Electric oven	Lifetime extension	↗				

De Kleine et al. (2011)	Residential central air conditioners	Lifetime extension	→				
Kim et al. (2006)	Refrigerator	Replacement	↗				
Ardente and Mathieux (2014)	Washing machine	lifetime extension	↗				
Kwak (2016)	Cell phones	Repair	↘				
Kwak (2016)	Washing machines	Repair	↗				
Intlekofer et al. (2010)	Computers	Lifetime extension	↘				
Intlekofer et al. (2010)	Appliances (washers, dishwashers)	Lifetime extension	↗				
Tasaki et al. (2013)	TVs	Lifetime extension	→				
Tasaki et al. (2013)	Air conditioning	Lifetime extension	→				
Tasaki et al. (2013)	Refrigerator	Lifetime extension	↗				
Cheung et al. (2018)	LCD projector	Remanufacturing	↘				
Bakker et al. (2014)	Refrigerators	Lifetime extension	↘				
Bakker et al. (2014)	Laptops	Lifetime extension	↘				
Perez-Belis et al. (2017)	Vacuum cleaner	Lifetime extension	→				
Bobba et al. (2016)	Vacuum cleaner	Lifetime extension	↘				
Raz et al. (2017)	Mobile phones	Remanufacturing	↗			•	
Esenduran et al. (2016)	Refrigerator	Remanufacturing	↗			•	
Esenduran et al. (2016)	LCD monitor	Remanufacturing	↘			•	
Esenduran et al. (2016)	Cell phone	Remanufacturing	↘			•	
Liu et al. (2017)	Refrigerators	Remanufacturing	→			•	
Thomas (2011)	Books	Reuse	↘			•	
Farrant et al. (2010)	Clothing	Reuse	↘			•	
Kerr and Ryan (2001)	Copier	Remanufacturing	↘	•			
Kwak and Kim (2016)	Desktop PC	Remanufacturing	→	•			
Sabbaghi and Behdad (2017)	Laptop	Lifetime extension	→	•			
Krystofik et al. (2017)	Office furniture	Remanufacturing	↘	•			
Tornese et al. (2018)	Pallets	Reuse	→		•		

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Good business practices for the transition to the circular economy. Case analysis and situation in Spain

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Abstract

The Circular Economy (CE) model seeks to improve the current linear production model to face global challenges such as climate change and resources overexploitation. However, the circular economy approach can be also a framework with a business scope that supports production on the regeneration of products and services from their design to their reincorporation into the productive system. The main goal with CE is to use fewer resources while maintaining the value of products, limiting at the same time the entry of raw materials and reducing negative externalities to the environment and public health from the linear production model. To strengthen the transition from a linear to a circular economy, it is important to develop integrated assessment systems able to adapt to different needs and contexts considering the correspondent economic policies, macroeconomic and microeconomic indicators. However, innovation is a key element that enables the incorporation of appropriate technologies, the improvement of production processes and business models, and the integral change on consuming behavior. On the other hand, learning from best practices and key cases can be the best way to move from the linear to the CE model. A previous research developed during 2016 with the exploration and analysis of most relevant companies working on CE in Spain, resulted in the report "Situation and Evolution of the Circular Economy in Spain" published by COTEC Foundation in 2017. The updated version has to be published in 2019. Previously to the analysis, a new indicator methodology to assess the state and extension of Circular Economy development was developed. The methodology is based in the use of five large groups of indicators: material input, ecodesign, materials use in production, materials use in consumption and waste recycling. This work provides an overview of the existing best practices and cases on Circular Economy in Spain (including companies of different sizes, non-profit and government organizations) where a growing evolution is observed going from 46 good practices in 2017, to 167 in the current 2019 report. It is worth mentioning that this is a novel approach for Spain, including the theoretical approaches related to the set of indicators used, the identification of key actors, and the successful cases and best practices quantified and analysed. Finally, our concluding remarks on the state of Circular Economy introduction in the different sectors in Spain are presented, although main barriers are also detailed.

Keywords: Circular Economy, Good practices in Spain, Indicators, Theoretical approaches.

1. Introduction

Economy is described as the science that studies the use of resources – from its production, distribution and consumption – employed in creating wealth and satistying human needs (Stiglitz, 1943). One of the main goals of the economic theory is the analysis of productivity that determines economic growth and decision-making both at national (macroeconomic) and at company (microeconomic) levels. This variable is analyzed through the productivity indicator that allows measuring and comparing the wealth between nations and companies, which in turn makes it possible to formulate the necessary policies for economic development and technological progress (Polák, 2017).

After the neolitic revolution that led to the transition from a nomad way of life to a sedentary one for human societies (Guzmán and Weisdorf, 2011; Roberts et al., 2018) the second relevant period in terms of social and economic transformation was the industrial revolution of 1760. Over this second great revolution for human society, craft processes – understood as slow production systems (Crouzet, 1969) – were replaced with a model based in technological and organizational development to achieve a faster production system. This change allowed the internationalization of world markets thanks to the rise on energy and cheap labor availability due to the relocation of production processes (O'Rourke, Rahman and Taylor, 2013).

The production model that originated in this first industrial revolution is still the prevailing one and is grounded on linear economy and unlimited growth (Kosoy et al., 2012; Bowerman, 2014; Sahakian, 2014; Giannetti et al., 2015). This means that big escale production and the internationalization of companies are prioritized to gain position in global markets and to generating greater economic benefits. A fundamental premise for this linear model – in reference to the way it works through open-cycle production processes – to work is the continuous extraction of natural resources that is linked to negative impacts on the environment (Kosoy et al., 2012; Cheng et al., 2019).

The linear economy consists on the extraction of natural resources (Cheng et al., 2019) used for the production, distribution and consumption of goods and services, and finally dispose waste (Sachs, 2005). The prevalecence of linear economy has fostered a development where the production and consumption variables come before the natural resources and waste variables due to their consideration as endogenous to the way companies work and strategic to generate wealth in a short period of time. Natural resources and waste in turn are considered as exogenous variables. In the case of natural resources the consideration is based in the premise that raw materials – such as fossil fuels – generally come from external sources like other companies or permits for the direct extraction from the environment. Waste is also considered as an external variable because responsibility is placed on consumers for their production and the public sector for their management.

Over the 20th century and the beginning of the 21st, it has been proved that the linear economy model has fostered growth globally at economic, demographic and even social aspects. However, it also proved the huge need to review the consideration of its exogenous variables due to its negative and irreversible impacts to the environment at a global level (IPCC, 2014).

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Before these limitations, sustainability appears as an alternative framework that allows analysing and creating strategies to avoid economic development from being isolated from social and environmental concerns. Sustainability is understood as any action aimed at maintaining the energy, informational and biophysical conditions that sustain all living beings. It seeks the continuity of natural cycles to meet both the needs of the present generation and future ones so that natural capital is maintained and its capacity for regeneration, reproduction and eco-evolution is fostered (WCDE, 1987; Biermann et al., 2012).

This expanded and integrative concept of sustainability should serve as a criterion to assess progress and serve as an inspiration or idea-generator to achieve greater sustainability in different fields of human activity (Kajikawa, 2008; Calleros-Islas, 2012). However, its been over 70 years since the concept was coined and one of its main limitations is the poor correspondence between a broadly developed theory and a practice reduced to descriptive statistics with little influence in the decision making spheres and the prevailing economic model (Moloney and Strengers, 2014; United Nations, 2015). A large number of researchers have concluded that sustainability still has a long way to go before the volume of conceptual discussion corresponds to the capacity to impact decision-making, plans and concrete actions (Böhringer and Jochem, 2007; Schlör, Fischer and Hake, 2014; Calleros-Islas, 2017).

Aiming to close this gap between descriptive and applied capacities of the sustainability approach, the Circular Economy (CE) model has appeared as an alternative to harmonize the pace of productive systems and natural systems and has become rapidly and broadly accepted at international level (European Commission, 2015; Lausselet et al., 2017; D'Amato, Korhonen and Toppinen, 2019). The CE model was first developed methodologically by the Ellen MacArthur Foundation proposing a substantial change in the productivity indicator and consumer behaviour to efficiently respond the globlal challenges such as climate change and sustainability (MacArthur et al., 2013). This is intended to be accomplished through reducing the material demand for production by closing the cycle of economic and ecological resources flux (Haas et al., 2015).

Nonetheless, as a novel framework it is still in need of a more roboust research and analysis foundation (Millar, McLaughlin and Börger, 2019). Our paper aims to provide some groundwork to the field of CE by analysing best practices and applied cases in Spain through a methodology based in five large groups of indicators: material input, ecodesign, materials use in production, materials use in consumption and waste recycling. With this exercise, we intend to contribute to the consolidation of the CE model and to provide more tools to facilitate companies and other stakeholders to apply CE principles. In order to accomplish this, our paper is structured as follows: section 2 is dedicated to outline the concept of CE before describing the methods employed in our study consisting on an extensive literature review and the detection of best practices of CE in the Spanish context; section 3 presents the discussion over our findings and the obtained results from the conducted analysis; finally, conclusions are gathered in section 4.

2. Methods

Our analysis started with a review on the CE model to provide a context that serves as a point of reference for the identification of good practices and the current state in Spain to observe how widespread the model is and what perspectives are to be expected in the near future. In order to facilitate the task, a methodology for the integrated assessment of CE was applied to measure how the model is actually impacting the way of doing business in the country.

Contextualization of the Circular Ecnonomy

The economic recession derived from the effects of the 2008 crisis led to reflect on how to get production processes to be more efficient and how to transition towards a productive model widely accepted but that would also complies with the international agreements on sustainable development and climate change (MacArthur et al., 2013) (EEA, 2016). For the Euroean Commission, that model is the Circular Economy (CE) that through the European Commission Action Plan for the Circular Economy (European Commission, 2015) pretends to revitalize the economies of the member States at local and national levels. The Action Plan for the CE proposes that member States improve their competitiveness through strenghthening the economic system in a more sustainable and resilient way, respecting the fact that resources are scarce and promoting innovations and business efficiency and radically changing production and consumption patterns (Avdiushchenko, 2018).

In sum, CE is an economy designed to prevent waste generation through reuse, remanufacturing and recycling (MacArthur et al., 2013; Ferronato et al., 2019). The result was an economic and industrial model based on restoration and regeneration from design that seeks to recover and reuse production surpluses and waste to reincorporate them to the productive system avoiding overexploiting natural resources (Morató et al, 2017). This is meant to maintain resources availability over longer periods of time in order to balance them with the Earth's regenerative cycles and together with business policies to improve processes with more efficient technologies will help in reducing material loss (CTCN, 2018).

CE was developed from other schools of thought such as permaculture to relate human beings and nature (Mollison, B., Holmgren, 1978); industrial ecology and the analysis of energy and material flows in industry (Frosch, R.A., Gallopoulos, 1989); cradle to crave and the importance of managing waste from design (Stahel, 1992); and biomimetics where nature cicles and processes are imitated (Benyus, 2001).

The UN 2030 Agenda on Sustainable Development approved in 2015 was another step that reinforced the model of the CE (UN, 2019). The Agenda consists of 17 Sustainable Development Goals (SDGs) with the objective that countries and their societies embark on a new path to improve the quality of life of all its inhabitants. Although the impact of the SDGs in the political sphere and in decision-making processes remains to be seen, their importance lies in the recognition that the search for answers to the great global challenges is carried out within the framework of sustainability, which is an important step towards the previous prevalence of economic growth as the only solution (Munasinghe, 2012; Allen, Metternicht and Wiedmann, 2016; Hák, Janoušková and Moldan, 2016; Calleros-Islas, 2019).

In economic terms, an enormous step has also been taken in directing efforts towards the CE as an answer to the rising need to close production cycles, generate employment of quality and promote the creation of capital at local level while reducing waste generation. Specifically, the CE can be found in objective 12: guarantee sustainable consumption and production modalities. However, it also directly influences the goals of ending poverty, sustainable energy, decent work and economic growth, innovation and infrastructure industry, reduction of inequalities, sustainable cities and climate action, in addition to the 3 relative objectives to natural

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resources.

Estimations show that to obtain raw materials more than 92 billion tons of natural resources are extracted annually from the environment and less than 10% is reused. Being fuelled by fossil fuels, production systems are causing the climate change effects observed worldwide as shown in material management being accounted for 67% of greenhouse gas emissions. On the other hand, if only current waste regulations were applied in the European Union it would create more than 400,000 jobs in the region and over 52,000 would be created in Spain. These evidences highlight the fact that human activities today are still inefficient both in terms of human well-being as in the impacts they generate to the environment (MacArthur et al., 2013; European Commission, 2015; Sevigné-Itoiz et al., 2015; CTCN, 2018).

Considering these facts, the need to implement alternatives like the CE is growing. For this, it is important to have reliable evaluation and monitoring methods that provide clear and efficient inputs to be used by decision makers and influencers. Integrated analysis through indicators is one of the options to determine the current situation and the desirable future situation in terms of a change in the current economic paradigm, specifically in the production and consumption model.

Literature review and identification of good practices methodology

The literature review consisted of an extensive internet search on the main keywords of the CE specially looking for initiatives developed in Spain including services, good practices and projects driven by companies, NGOs, universities and Public Administrations. After this search on commonly used databases and search engines, we extended the search to the European Projects database including Horizon 2020 and LIFE Projects. The analysis we conducted was made in two periods from January to August of 2017 and from January to August in the present 2019 as part of the UNESCO Chair of Sustainability and the RECNET Network preparation of two reports for the COTEC Foundation (COTEC, 2019). This led to the selection of 167 cases found in academic papers, reports and project reports. From this total, the initiatives that applied the CE principles in a broader sense were selected as good practices.

Figure 1 shows a methodology that was develoed for the integrated assessment of CE experiences and applications. This was made through indicators that correspond to the 5 main dimensions of CE: material input; eco-design; material use in production; material use in consumption; and finally waste management and recycle (European Commission, 2015; Morató et al, 2017). Another thing to point out is the innovative incorporation of the demand side in the CE model – as shown in the lower left corner of Figure 1 –, recognizing that consumption must be managed as well in order to decrease environmental impacts and social inequalities.

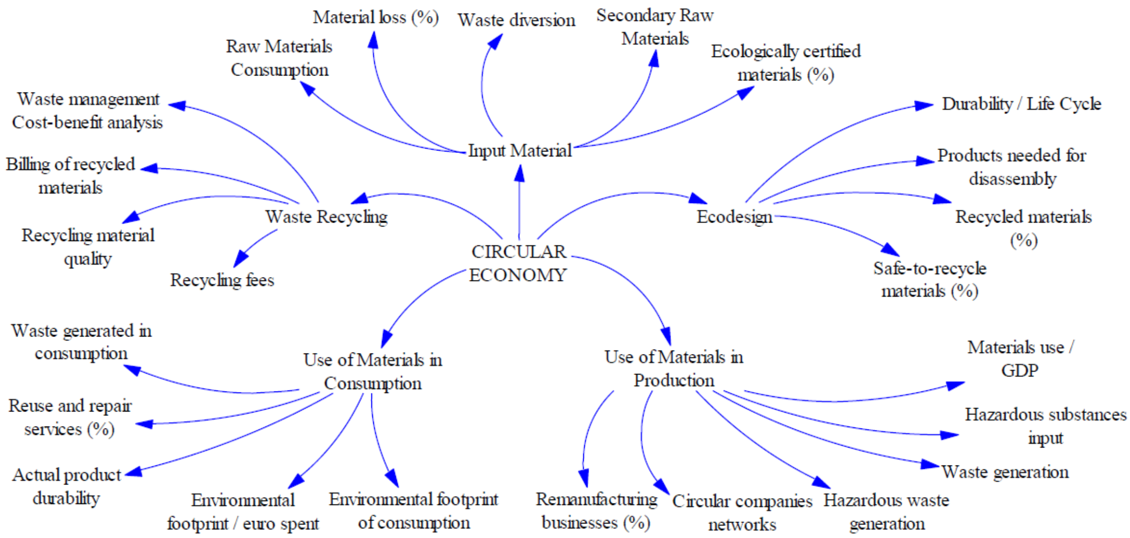

Figure 1. *Circular economy integrated assessment system. Prepared by the authors from Morató et al, 2017.*

3. Results and Discussion

Innovation is recognized as a key element for the advance towards a CE and this is translated in the need for new technologies and processes that allow an integral shift in the production-consumption chain. The identification of good practices in the field is a way to consolidate the application of CE principles and to foster the dissemination of the model all over Spain.

One of the main results is that using the same methodology, after only two years a significantly higher number of experiences were obtained from both the internet search and the European research programs. A growing evolution is observed going from 46 experiences in 2017, to 167 in the current 2019 report (Morató et al, 2017). However, we also observed that some companies and consortiums are incorporating the nomenclature without really representing any change at practical level showing that the term is being instrumentalized as an incorporation of the fashion term of the moment. The results showed that in general, experiences related to CE are focused on a section of the life cycle of a product and only a few incorporated a broader scope of analysis and application.

In spite of that, it is considered that the highlighted organizations cover the main objectives of the Circular Economy in terms of preventing waste, reducing environmental impacts and revaluating obsolete objects and materials. The total of 167 experiences that is listed in the 2019 COTEC Foundation Report (COTEC, 2019), is more than 3 times bigger than in 2017 considered as a first attempt to gather initiatives in Spain in terms of CE and is meant to serve as a repository that fosters the creation of business networks and hubs.

In terms of the share each cathegory of the CE represents from the total of experiences, waste recycling is the one with more weight with over 50% of the cases in both of the analysed periods. In second place, eco-design represents 19% and production related cases in third place with 18% and both cathegories had the same outcome in 2017 and 2019. Cases and projects related to consumption have grown from a 6% in 2017 to a 10% of the total in 2019. Finally, the weight of projects related to material input are still close to none going from 0 projects in 2017 to a 2% in 2019.

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The cases selected as good practices for their broad incorporation of CE principles is shown in Table 1. From the total of 19 good practices, 12 are related to waste prevention, management and reuse which is considered in accordance to the CE principles since it is considered as the trigger point of the linear economy model. Only 2 are related to the social sectors and just 1 aims to influence policy making.

Table 1. *Good practiceshighlighted for the broad application of the Circular Economy model. Prepared by the authors from COTEC Reports2017 and 2019.*

Year	Company / Project	Good practice	Description / Goal
2019	ORANGE FIBER	Textile production from orange skins	Process to close the cicle of citric waste
2019	FAIRPHONE	Modular and ethical Smartphone	Useful life extension through reuse and recycling
2019	PORTA PALAZZO	Organic farming Project	Reduce food waste
2019	RÄUBERSACHEN	Baby clothes rental	Organic, high quality and durable clothes rental for babies
2019	NATURGY	Renewable gas project: Edar de Bens	Increasing productive processes and applications of renewable gas from residual muds
2019	Plastic Energy	Plastics regeneration	Plastic waste recycling and detouring from wastelands and oceans
2019	REPSOL	Circular Economy Strategy	Development of Circular Economy projects
2019	MERCADONA	New Store Models	Reusable packaging and containers in stores
2019	Comarca del Vallés Occidental Cataluña	Towards a transition to the Circular Economy	Boost economic development, social and environmental policies
2019	ECOEMBES	Creation of a “TheCircularLab” to activate Circular Economy	Study the phases of the life cycle of containers
2019	Aguas de Barcelona	Circular Economy Strategy	Reduce resources consumption, waste and the use of by-products
2017	ANFEFI	Glass and Circular Economy	Social iniciative for recycling glass containers
2017	CETAQUA	Circular Economy in Sant Feliu de Llobregat	Boost the preservation of natural resources and decrease CO_2 at municipal level
2017	ECOTIC	Recycling to create	Electric devices waste management
2017	NEOELECTRA	Energy solutions	Cogeneration, biomass and biogass projects
2017	SOLUTEX	Unique products development	Technological solutions for farmaceutical products
2017	TECNALIA	Sustainable construction and energy	I+D+I applied to energy, industry, urban habitat and infraestructures
2017	ECORKWASTE	Viability assessment of	Waste prevention through revaluatin cork
		cork by-products	by-products

2017	REAGRITECH	Sustainable management system for waste water from agriculture	Closing the water cycle through purifying waste waters from agriculture with natural methods to return to aquifers

4. Conclusions

Through the review and analysis of specialized literature, it is concluded that the circular economy (CE) is constituted as a new production and consumption model that is already determined to be put to practice in order mitigate the negative effects of the current linear economy model. Proof of this is that international institutions such as the UN and the European Commission incorporate it as a key element in their respective agendas.

One of its main strengths is that CE has a theory strong enough to foster academic dialogue, but also compact enough to present as a manageable and easy to implement alternative at organization level. The resulting concept is more concrete and therefore easier to incorporate as "good practice" both in public and private sectors. However, given that the CE also intends to change consumption patterns of society, it is also necessary to develop and implement policies from the public administration and private companies to encourage the much needed transition. This is one of the main obstacles faced by the model, since it is more complex to implement these mechanisms and they often fall short for modifying consumer behaviour.

It is also observed that when dealing with a new approach, there are still unknown frequencies in terms of the impacts that may have a long term. This impacts can either be positive, such as waste reduction, greater efficiency of production processes, relocation and reduction of environmental impacts –, or negative like the slowdown of the economy, difficulty in influencing the demand side, probable decreases in production, etc.

This paper was first attempt to gather initiatives in Spain in terms of CE and is meant to serve as a repository that fosters the creation of business networks and hubs. The next stage will cover the application of the methodology to the cases identified as best practices to foster the application and dissemination of the CE principles.

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Enabling industrial symbiosis. Potential drivers and barriers

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Abstract
We currently live in a society where the business model of companies is based on extracting, manufacturing, using and wasting. However, this is not sustainable over time and hence, it is where the circular economy comes into play and tries to ensure that resources in general maintain their value at all times. In this sense, industrial symbiosis can help in the objective of the circular economy, encouraging collaboration between companies. These companies might improve their competitive advantage through exchanges of materials, energy, water and by- products. Although there are several documented cases of industrial symbiosis that show the benefits of their adoption, industrial symbiosis collaborations are still scarce and difficult to initiate. The objective of the study is to analyse the barriers and facilitators to help future companies to implement industrial symbiosis in the most appropriate way possible. This research has been carried out through a bibliographic review where VOSviewer software has been used to identify areas in which more studies have been done and the importance of drivers and barriers in the studies that exist until today. In addition, an exhaustive analysis has been carried out to identify the barriers that can slow down in the implementation of industrial symbiosis and the drivers that can accelerate such implementation. These drivers and barriers are related to availability and access to information, economic and technical aspects, regulations and organizational and social problems. The lack of available financial support and the large investments required are part of the main barriers to the development of industrial symbiosis networks. As explained in this article, many of the barriers identified are also part of the drivers. It is therefore important to have facilitators that may help to achieve collaboration between companies and spread the benefits of industrial symbiosis, thus achieving the path to the circular economy.

Keywords: Industrial Symbiosis, Drivers, Barriers, Case Studies

1. Introduction

We live in an environment in which there is a frenetic pace of production and consumption, where the business model of companies is based on taking, making, using and wasting. Therefore, we have been immersed in what is known as linear economy. However, this is not sustainable over time and that is where the circular economy comes in. Circular Economy aims to prevent the depletion of resources, close energy and materials loops and facilitate sustainable development (Prieto-Sandoval et al., 2018). Businesses, governments and citizens areincreasingly aware of the importance of the circular economy and there are more and more actions that we can appreciate around this concept.

The circular economy tries to keep the value of things as long as possible. This has as a consequence great advantages: decrease in the use of raw materials, decrease in waste, decrease in costs, lower environmental impact. In this sense, companies can collaborate together to close loops and get mutual benefits, this is known as Industrial Symbiosis (IS). IS has been defined as engaging "traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products" (Chertow, 2000). In most cases, when we talk about industrial symbiosis, we think that the waste of a company can serve as a raw material for another company. However, the industrial symbiosis goes further and, in many cases, joint transport agreements, machinery sharing and even facilities can be reached.
Some of the industrial symbiosis cases that we can find in the literature are shown in Table 1.

Table 1. *Industrial symbiosis cases.*

Case	Main factors	References
Austria, Styria	• Researchers uncovered a network with a high degree of diversity and complexity, with exchanges consisting of hundreds of thousands of tons of materials • Styrian companies were not generally aware of the network of regional material flows • Importance of a coordinative function to try to increase exchange and improve internal and external communication	(Chertow, 2007)
China	• Chinese government's adoption of the eco-industrial park (EIP) program to benefit both economic development and the environment • Government policy guidance, advertising and financial support • Development of a national demonstration of the eco-industrial park • Main drivers: economic benefit, society and corporate culture factors, increase of environmental protection investments, encouragement provided by tax cuts and refund policies	(Yu et al., 2015)
Denmark, Kalundborg	• Small size of the community involved • Already established acquaintance of the managers • Good communication	(Chertow et al., 2004; Costa and Ferrão, 2010)

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	• Network of relationships between industrial managers and with regulatory authorities • Spontaneous development	
Finland, Finish forest industry	• Tightened legislation (non-renewable resources, emissions to nature, land use, impacts on human health and society) • Technical innovations	(Pakarinen et al., 2010)
Portugal	• Portuguese government issued the Law Decree 3/2004, with the objective of calling for a new approach to hazardous waste management • Implementation of middle-out approach	(Costa and Ferrão, 2010)
United Kingdom	• Establishment of a national IS programme (NISP) which will act as an umbrella for different regional programmes, facilitate information exchange and provide feedback regarding environmental sustainability • Fiscal incentives for IS programs. UK environmental policy and legislation	(Mirata, 2004)

Although there are several documented cases of IS showing the benefits of adopting it, IS collaborations are sometimes difficult to initiate (Chertow, 2007). These cases of industrial symbiosis have been created in most cases from the design; that is, from the creation of the companies themselves. However, there is not much evidence in the literature of industrial symbiosis between companies that have been operating for years. Therefore, the main objective of this study is to analyse the barriers that can prevent companies from entering in an industrial symbiosis and analyse the drivers that can promote the implementation of a symbiosis.

Consequently, this study will help organisms, scientific community, governments, etc. work to minimize these barriers and for companies to rely on the drivers they can find by implementing symbiosis.

This paper is divided into four sections. Following this introduction, Section 2 describes the research method used to pursue the objective. Section 3 analyses the outcomes of our systematic literature review and content analysis to determine the barriers and drivers that might arise when implementing IS. Finally, Section 4 concludes with a summary of the main research results.

2. Methods

A literature review has been carried out to identify the drivers and barriers that may arise when implementing industrial symbiosis. A literature review is an analysis of the relevant available research and non-research literature on the topic being (Hart, 1999). It assists on defining the context in which the study will be established and narrowing down the scope of the research into a manageable project (Webster and Watson, 2002). It should contain a clear search and selection strategy (Carnwell and Daly, 2001). Consequently, the first step to carry out a literature review is to define a set of keywords. In the case of this research, the following groups of keywords were created with terms that had related meanings (Table 2).

Table 2. *Keywords for the search query.*

Groups	Keywords
Group 1: Sustainability	“circular economy”, “sustainab*”, “industrial ecology”
Group 2: Industrial Symbiosis	“synerg*”, “symbiosis”, “collaborat*”
Group 3: Drivers and Barriers	“driver*”, “enabler*”, “facilitator*”, “opportunit*”, “barrier*”, “difficult*”
Group 4: Companies	“compan*”, “enterprise*”, “industr*”

From these groups of words, a query or search algorithm was designed for the Web of Science database and the search fields selected for the recovery of the scientific literature was the Topic (TS). Topic fields include Titles, Abstracts and Keywords. The final algorithm is shown in Table 3.

Table 3. *Query algorithm.*

Query algorithm: (Group 1) AND (Group 2) AND (Group 3) AND (Group 4)
TS =("circular economy" OR “sustainab*” OR “industrial ecology”) AND TS =(“synerg*” OR “symbiosis” OR “collaborat*”) AND TS =(“driver*” OR “enabler*” OR “facilitator*” OR “opportunit*” OR “barrier*” OR “difficult*”) AND TS =("compan*" OR "enterprise*" OR "industr*”)

A total of 1,656 results were obtained and inserted in the VOSviewer scientometric software. This software allows us to calculate, among other things, the keywords frequency (Van Eck and Waltman, 2009). As a result, a two- dimensional map is obtained, and in which the words are organized according to their similarity. Those words that have a greater similarity will be near to each other (Van Eck and Waltman, 2009).

The 1,656 results were then ordered in the Web of Science database according to the relevance of the query. To ensure the quality of the results, a review performed manually of each of the papers was conducted and only those that had a direct relationship with drivers or barriers in an industrial symbiosis context were selected. This review was carried out in two stages; initially we reviewed the abstract to verify that the articles met the aforementioned criteria keeping them on a waiting list. Afterwards, a full reading was completed to decide whether to keep them or discard them. With the final list of results (40 articles) an analysis of the main drivers and barriers was done.

3. Results and Discussion

The 1,656 articles that came out of the WOS search were analysed with the VOS Viewer. The unit of analysis selected was "Author keywords" with a "Co-occurrence" analysis where the relatedness of the keywords is determined based on the number of documents in which they occur together.

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3,764 keywords were analysed and to check those that appear most frequently in the articles, a threshold of a minimum of 10 occurrences was marked for each keyword obtaining a total of 35 keywords. In addition, those words that were not related to the search criteria such as "innovation", “education”, "higher education", "research" and "open innovation" will be eliminated. The keywords that are shown in Table 4 are the 5 words that most appear in the articles and are also those that have a greater "total link strength". The "total link strength" measures the number of times each keyword appears with other keywords in the same article.

Table 4. *The most relevant keywords.*

Keyword	Occurrences	Total link strength
Sustainability	165	117
Industrial ecology	81	84
Industrial symbiosis	79	91
Sustainable development	76	66
Circular economy	52	65

In Figure 1, the keywords with more occurrences can be seen, since they are represented with a larger size. The colours represent the different sub-fields or clusters. Clustering determines the similarity between the most used keywords and provides indications of the most concentrated points in the research field (Cui, 2018)

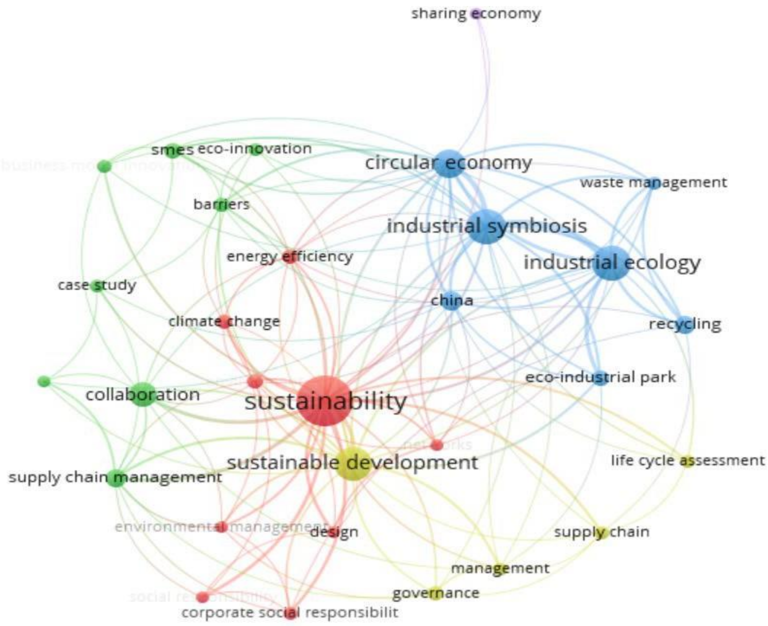

Figure 1*. Keywords' network.*

As it can be observed, sustainability is the keyword with the most occurrences and with the most relationships. As it is a fairly generic keyword, it is understood that it appears in a large number of articles. Industrial symbiosis and industrial ecology have appeared with practically the same frequency.

It should be noted that barriers appear only in 15 articles and drivers only in 9 articles, so the latter does not appear on the network. In addition, the relationship of these two keywords with industrial symbiosis is very limited, since there are hardly any studies that have analysed the causes that can impede companies from implementing the industrial symbiosis and what potential drivers can help them.

As previously mentioned, the abstracts of the articles of the WOS search were read and the complete articles of those that fulfilled the search criteria were read. Finally, only 40 articles mentioned in their study characteristics related to barriers and drivers in the industrial symbiosis.

The following table (Table 5) shows the most relevant barriers that have been identified through the analysis of the literature.

Table 5. *The most relevant barriers.*

Barriers	References
Lack of trust among locators, in new partnerships. Lack of willingness to collaborate. Lack of intercompany cooperation.	(Bacudio et al., 2016; Ceglia et al., 2017; Golev et al., 2015; Gordon et al., 2012; Jensen et al., 2012; Patricio et al., 2018; Walls and Paquin, 2015)
Lack of information sharing among locators	(Bacudio et al., 2016; Domenech et al., 2019; Dong et al., 2016)
Lack of top management support	(Bacudio et al., 2016; Ormazabal et al., 2018; Zhu et al., 2015)
Lack of an institutional support. Deficient institutional framework. Lack of policy to incentivize IS	(Bacudio et al., 2016; Kirchherr et al., 2018; Liu et al., 2015)
Legislation and regulation, policy. Too restrictive regulation. Fragmented regulation systems	(Behera et al., 2012; Dong et al., 2016; Geng and Doberstein, 2008; Golev et al., 2015; Mathews and Tan, 2011; Pajunen et al., 2013; Papathanasoglou et al., 2016; Walls and Paquin, 2015)
Lack of technology and infrastructure readiness	(Bacudio et al., 2016; de Abreu and Ceglia, 2018; Dong et al., 2016; Kirchherr et al., 2018; Ormazabal et al., 2018)
Lack of time	(Domenech et al., 2019; Patricio et al., 2018)
Lack of training for implementing IS. Lack of awareness of IS concepts. Lack of knowledge/information. Inadequate information system	(Bacudio et al., 2016; De Jesus and Mendonça, 2018; Dong et al., 2016; Geng and Doberstein, 2008; Golev et al., 2015; Mauthoor, 2017; Ormazabal et al., 2018; Papathanasoglou et al., 2016; Patricio et al., 2018; Watkins et al., 2013)
Lacking consumer awareness and interest. Rigidity of consumer behaviour.	(De Jesus and Mendonça, 2018; Ormazabal et al., 2018)
Lack of funding to promote IS. Lack of economic incentives for companies to purchase "second hand" materials. Lack of market incentives to reuse waste.	(Bacudio et al., 2016; Geng and Doberstein, 2008; Papathanasoglou et al., 2016; Winans et

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Barriers	References
	al., 2017)
Risk and uncertainty linked to difficulty to identify costs-benefits and return on investment	(Domenech et al., 2019; Golev et al., 2015; Pajunen et al., 2013; Walls and Paquin, 2015)
High investment and transaction costs. Large up-front capital investments.	(Domenech et al., 2019; Kirchherr et al., 2018; Mathews and Tan, 2011; Pajunen et al., 2013; Teh et al., 2014)

As it can be seen in Table 1, the list of barriers when implementing industrial symbiosis is wide. There is a first block of barriers related to the lack of collaboration between local companies. Companies do not feel comfortable sharing information with other companies and therefore joint collaboration is difficult.

On the other hand, there is a lack of commitment from the company's management and lack of institutional support that encourages the implementation of industrial symbiosis. In many cases, the law is very restrictive and makes collaboration between companies difficult, since for example the waste of a company cannot be sold directly to another company.

In addition, people and infrastructure are not currently prepared to face this change since people need training and in some cases the implementation of actions for promoting industrial symbiosis requires a change in technology or infrastructure and time.

Many companies have not detected an awareness on the part of their clients since these are, in many occasions, reluctant to any change.

Finally, a great barrier that becomes known in different ways is the economic issue. Companies demand economic incentives and yet do not find them. It is also difficult for them to identify the benefits that they will obtain against the costs that they have to face since they consider that the investments to be developed are very restrictive.

However, many of these barriers are seen as drivers in many companies. Table 6 shows the most relevant drivers that push companies to implement industrial symbiosis.

Table 6. *The most relevant drivers.*

Drivers	References
Create new areas of revenue. Increase turnover for the company. Decrease company costs through the use of secondary material	(Domenech et al., 2019; Ormazabal et al., 2018; Pakarinen et al., 2010; Patricio et al., 2018; Walls and Paquin, 2015; Yu et al., 2015; Zhe et al., 2016)
Funding, financial support, financial incentives	(De Jesus and Mendonça, 2018; Mortensen and Kørnøv, 2018; Teh et al., 2014; Valentine, 2016; Yu et al., 2015)

Legislation and government regulation. Increasing environmental legislation and environmental standards	(De Jesus and Mendonça, 2018; Mortensen and Kørnøv, 2018; Pajunen et al., 2013; Pakarinen et al., 2010; Teh et al., 2014; Walls and Paquin, 2015; Yu et al., 2015)
Building new partnerships with other companies. Trust and cooperation among diverse partners. Collaboration.	(de Oliveira et al., 2018; Domenech et al., 2019; Mulrow et al., 2017; Teh et al., 2014; Valentine, 2016; Walls and Paquin, 2015)
Effective information management. Information sharing. Access to knowledge.	(Liu et al., 2015; Mulrow et al., 2017; Teh et al., 2014; Valentine, 2016; Zhe et al., 2016)
Third bodies such as governments, industry associations and research and education institutions as facilitators or coordinators.	(de Abreu and Ceglia, 2018; de Oliveira et al., 2018; Mortensen and Kørnøv, 2018; Walls and Paquin, 2015
Achievement of company's environmental policy and targets. Change to a more a sustainable business model. Corporate social responsibility. Corporate culture	(Domenech et al., 2019; Ormazabal et al., 2018; Pajunen et al., 2013; Valentine, 2016; Yu et al., 2015)
Access to innovation. Replacement of out of date technology with state-of-the-art technology Acquiring new clients	(Domenech et al., 2019; Teh et al., 2014) (Domenech et al., 2019)
Marketing reasons	(Patricio et al., 2018; Teh et al., 2014)
Social awareness. Stakeholder pressure and general public pressure	(De Jesus and Mendonça, 2018; Mortensen and Kørnøv, 2018; Teh et al., 2014; Walls and Paquin, 2015; Yu et al., 2015)
Geographical proximity. Small geographical scale	(Mortensen and Kørnøv, 2018; Mulrow et al., 2017; Teh et al., 2014; Walls and Paquin, 2015)
Awareness of the waste and by-products flows that are available for utilization	(Pakarinen et al., 2010)
Reduced dependency on developed countries for the importation of raw materials	(Chertow, 2007)

In this case, the economic aspect is seen as a driver. Companies find drivers in the industrial symbiosis to reduce their costs. They also consider that the economic aid that exists pushes companies to implement the industrial symbiosis. In this sense, it should be noted that the economic aspect is very important for companies. When agencies or institutions give aid or incentives, companies are motivated and get more involved and when they do not receive that help, their interest declines.

Also, in the drivers is a factor previously identified as a barrier: collaboration and trust between different agents. It is seen as an opportunity to share information, improve processes and costs thanks to the joint work with other companies. In this sense, it seems very enriching to have facilitators to accompany and help in this

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creation of collaboration. These facilitators can be public agents, associations, universities or research centers.

Companies also believe that industrial symbiosis can help them achieve a more sustainable business model that meets the objectives of the company's environmental policy. In addition, the industrial symbiosis will allow them to innovate, thus obtaining new customers.

Although the barriers commented that customers were not aware and did not demand changes to companies; in this case it is clearly observed that there is a social awareness that pressures and demands a change from the companies. In this way, it can be affirmed that we are facing a change where although there are still clients who do not see the change towards a circular economy necessary, there is a strong social pressure that is changing the course of companies.

Finally, it should be noted that the proximity between companies can help establish collaborations. In addition, industrial symbiosis can help companies realize that they can take advantage of waste or by-products from other companies, thereby reducing dependence on raw materials.

4.Conclusions

This study has allowed us to assess the barriers that exist today in the implementation of industrial symbiosis. It is important to take them into account in order to minimize them. The drivers that companies can find when they implement industrial symbiosis have also been identified.

It should be noted that as it has been observed in this study, many of the barriers that have been identified coincide with the drivers. It is therefore necessary that all the agents involved do their part: public administrations, clients, associations, companies, etc. It is important that the different agents go one on one and bet on sustainability.

In this sense, facilitators such as public agents, universities, associations or research centres can act as drivers of industrial symbiosis actions and fruitful collaborations. In addition, these facilitators may be responsible for many of the identified factors being seen as drivers and not as barriers, emphasizing the benefits that collaboration between industries can bring. In this sense it is important that facilitators create a framework of collaboration where companies feel comfortable to exchange information and where a climate of trust can therefore be created.

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Problematic Plastic Waste: 6 ways to increase circularity

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Abstract

The increasing issue of plastic waste is really (at least) two separate but related problems when plastic materials drop out of use or circulation. First, some plastic items have an entirely linear lifepath because of the way they are constructed, the materials they use or the purpose to which they are put. The best possible outcome for such plastics would be to sit in landfills for thousands of years, contributing to issues of landfill volume and long term maintenance. Second, some plastics items are more likely than others to be disposed of improperly after which they become visible litter in natural areas or invisible microplastic contamination in water, soil, food and even human bodies. Even when the plastic in these products is recyclable, the material is not captured effectively in waste collection systems and leads to an accidentally linear lifepath. Fortunately, both problems can be addressed by introducing more circularity into the design, use, recovery and processing of plastic. Plastic wastes can be made less linear if they are averted through the use of more circular materials, minimised by decreasing the amount of plastic used, delayed if reused rather than replaced after a single use. Even if minimised or delayed, plastics that cannot be averted could be recycled in various mechanical and chemical ways, which will be most effective if plastic is simplified as well as captured and processed in innovative ways. Finally, the energy embedded within plastic waste can be recovered if the wastes are burned for energy production or if plastic-consuming microbes are developed that can use plastic as an input to biological processes. None of these methods are applicable to all possible plastic waste situations nor are the methods completely free of problems of their own. This paper describes the factors contributing to both plastics problems and identifies the strengths and weaknesses of each of the proposed methods to address those problems. Finally, the paper explores how multiple methods can be combined through innovations in multiple societal arenas to create a mixed solutions that turns the current ‘linear plastic lifepath’ into a future ‘circular plastic lifecycle’.

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1 Introduction

Products and product packaging always use resources and energy in their creation, transport, use and disposal, but virgin materials typically require more resources and energy than recycled or reclaimed materials. Thus, re-manufacturing or re-using products or packaging creates a more efficient and sustainable circular lifecycle, in which the total resources and energy per use decreases with each trip though the cycle. In contrast, products or packaging that use virgin materials and that do not return these materials for re-manufacturing or re-use creates a less efficient and less sustainable linear lifepath. The total resources and energy per use for linear lifepath items is much higher than for circular lifecycle items, but further resources and energy must be expended to manage those items when they become waste.

Plastic represents a very important advance in material sciences because it has many novel and useful material properties including durability and recyclability (Geyer, Jambeck, & Law, 2017). As such, plastic could have a very circular lifecycle, but in practice plastic is too often used in ways that create very linear lifepaths. Essentially, plastic's material properties are not well matched to how it is used or managed so that plastic waste contributes to accelerated landfill use and ecosystems damage including physical obstructions (e.g. animals become entangled or starve after mistakenly eating plastic) and pollution as some plastics release harmful chemicals over time. The mismatches between plastics material properties and the ways that it is used or managed can be understood as at least two separate, but related, issues in which choices are made that lead to linear lifepaths instead of circular lifecycles.

The first issue is that many plastic products are deliberately designed, manufactured, marketed and used in linear ways that take advantage of some of plastic's material properties but that ignore or even actively work against oth- ers. For example, same products are made out of plastic in order to be lightweight, inexpensive, or colourful whilst simultaneously intended to be disposable. In effect, these plastics products are designed to have a linear lifepath even though the material has significant circular lifecycle potential. The second problem is that some plastic products are used in ways or in circumstances that prevent them from being effectively re-used or recycled. For example, empty single-serving plastic drinks bottles are promoted as convenient options but are unlikely to be recycled unless there is a convenient plastic recycling bin. Consequently, the highly recyclable plastic drinks bottles often end in linear lifepaths by accident as a result of how the products are actually used. It is also possible that a single product might have a linear lifepath as a consequence of both design choices and accidents of circumstances, as when single-servings of snacks are packaged in plastic that is not widely recycled and are also marketed as being convenient for eating on-the-go when convenient recycling bins are not guaranteed.

Importantly, the issues of linear lifepaths or circular lifecycles apply to all kinds of materials, not just plastic. Biodegradable materials, such as paper, cotton, hemp or biodegradable plastic-like cellulose can also be re-manufactured or re-used to improve the resource and energy per use. However, when biodegradable materials are not captured within a circular lifecycle, they will not accumulate in the environment or contribute to landfill use or environmental degrada- tion the way that plastic does; by definition, biodegradable means being part of a long but circular lifecycle of natural resource recovery and use. Non-biodegradable and non-plastic materials, such as metal, glass or ceramic, can also be re-manufactured, re-used and recycled as part of a circular lifecycle to improve the resource and energy per use. Being non-biodegradable, linear lifepath items made from these materials could contribute to landfill use and environmental deterioration. However, if these materials are valuable (e.g. gold, copper, etc.) then there are typically widespread and reliable methods for capturing and recycling. Less valuable materials (e.g. ceramics) are unlikely to have methods or systems for capture and recycling, but these materials also do not carry all of the same risks of contamination that plastics carry. It is clear that linear lifepath items made from either biodegradable or non-biodegradable but non-plastic materials are not as efficient or sustainable as circular lifecycle items and are not problem-free. Nevertheless, as the material properties of these plastic are unique, the problems arising from linear lifepath plastics are worth addressingseparately.

To summarise, this paper explores the particular factors driving plastic into linear lifepaths and how these factors might be addressed in five parts. First, a brief history of plastic and plastic disposal leads into the identification of problems associated with plastic waste. The second section identifies specific issues underlying linear lifepaths that are a result of deliberate design choices, followed by a section that identifies specific problems of linear lifepaths that are a result of unintentional interactions between design and use. The fourth section adapts the well-known '5 R's' (Refuse, Reduce, Reuse, Repurpose, and Recycle) into a framework with six different methods for increasing the circularity of plastic. This section also includes a discussion of how each method might interact with the others, positively or nega- tively, within larger patterns of plastic circularity. Finally, the paper ends with a conclusions section which highlights how innovation in multiple societal arenas may be needed to maintain a mutually reinforcing combination of methods for turning linear plastic lifepaths into circular plastic lifecycles.

2 History of plastic management

'Plastic' can be understood to include natural rubber as used by humans since at least the year 1600 (Andrady & Neal, 2009) but is frequently used to refer to synthetic polymer materials, the first of which was bakelite, invented in 1907 (Crespy, Bozonnet, & Meier, 2008). Later developments, including lower production costs, and lighter weight, lead to large-scale production by the middle of the twentieth century (Geyer et al., 2017) as plastic became a popular for commercial production of household and everyday items. Toward the end of the twentieth century, plastic found a new market in packaging (Geyer et al., 2017) which would typically enter and end its use within a single year.

As use of plastic grew, so too did awareness of the need to deal with it as waste (Bernardo, Simões, & Pinto, 2016). Most of the plastic ever produced (approximately 60%) is accumulating as waste (Geyer et al., 2017). Landfill is, by many ranking systems, a terrible option (Bernardo et al., 2016) although it is preferable to plastic waste accumulating in the environment. When plastic waste accumulates in marine and terrestrial ecosystems, it can cause physical obstruc- tions, chemical reactions, and opportunities for invasive species to enter new territories, among other problems (Webb, Arnott, Crawford, & Ivanova, 2013).

One alternative to allowing plastic waste to accumulate is to incinerate it. Plastic has a high embedded energy content, so can be usefully burnt to recover energy. Unfortunately, some waste incineration is not connected to energy recovery systems, so the energy potential of plastic waste incineration is sometimes squandered. Even more problem- atically, incinerating plastic waste is associated with air pollution (Al-Salem, Lettieri, & Baeyens, 2009), regardless of whether the energy potential within the plastic material is recovered or not. Thus, the value of incineration as a solution for managing plastic waste depends on several other factors, including

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the presence and/or efficiency of any energy recovery systems attached to the incinerator and the effectiveness of any pollution filtering systems applied to air outlets.

Although incineration is ranked higher than landfill for plastic waste, recycling is typically ranked highest as most of the most popular plastics are recyclable (Marsh & Bugusu, 2007). Nevertheless, plastic recycling is not without

problems. Primary recycling is the most circular option as it returns an output that is comparable to its input, although it only works with specific types of clean plastic (Al-Salem et al., 2009). Consequently, primary recycling is appropriate for industrial scrap plastic but less so for post-consumer plastic. Mechanical recycling has been popular since the 1970's and generally involves several stages of separation, cleaning and processing but is a viable option for many kinds of plastics that are not suitable for primary recycling. However, the output of mechanical recycling is typically used for different purposes than the input, so that recycled plastic drinks bottles are typically made into textiles rather than into new drinks containers (Al-Salem et al., 2009). Chemical recycling can turn plastic waste into a useful input to other chemical processes, such as creating petrochemical fuels and new plastics, and can tolerate mixed or dirty plastics as an input (Al-Salem et al., 2009).

Most plastics are not eligible for the few recycling processes that return an output of comparable quality to the input. Thus, recycled plastic inevitably cascades down in value each time it is recycled, creating a corkscrew lifepath that is ultimately linear although longer and more circular than were the plastic to be sent to landfill or incineration. As the problems with plastic recycling become more apparent, interest has grown in re-usable plastic (Al-Salem et al., 2009; Ross & Evans, 2003) but doing so comes at a cost as more durable and re-usable plastics are typically more expensive to produce and heavier.

3 Linearity

As a synthetic material, all plastic must have been manufactured in a intentional process. Similarly, any product or package that uses plastic does so as the result of a deliberate choice to take advantage of the material properties of plastic. Some of those choices lead to a linear lifepath for the plastic in question, which is to say that they are created from virgin materials, used once and then disposed of without any attempts to capture the plastic for re-manufacturing or re-use. The choices underling such linear plastic lifepaths can create that linearity by design, by accident or both.

3.1 Linear by design

The most obvious way that plastic wastes are linear by design is when they are ”single-use” as an intended feature. Single-use is not synonymous with linear-by-design, as single-use plastics could potentially be recycled. Nevertheless, many of the factors that lead to plastic being used in single-use products or packages means that those plastics are often used in contexts when recycling is not possible or at least not (currently) likely.

For example, plastic is biologically inert, very malleable, and inexpensive which make it ideal for maintaining hygienic conditions and airtight seals on food, drink, health and beauty products where cleanliness and hygiene are important. More recently, plastic wrappers, sheaths or films reduce the risk of contamination in medical, dental and other clinical contexts only if disposed of after each use (Hammon et al., 2014; Pollington, Kahakachchi, & van Noort, 2009). This clinical plastic waste is often excluded from recycling streams due to concerns over infectious potential (McGain, Hendel, & Story, 2009). Thus, despite being ineligible for recycling, single-use plastic in a clinical setting is still considered a practical and cost-effective solution to preventing cross-contamination (Pollington et al., 2009).

Similarly, cosmetic products are meant to be washed or wiped away, so plastics in cosmetics cannot be recaptured for recycling, much less incineration or landfilling. However, the low cost of plastic means that cosmetic products are still made with micro-plastics that are linear by design including as glitter (Napper, Bakir, Rowland, & Thompson, 2015) and (until recently) exfoliating beads (Cheung & Fok, 2017). In this way, the material properties of plastic make it ideal for use in health, beauty, food, drink and similar contexts, but those contexts also lend themselves to deliberately linear lifepaths.

The low cost of plastic also makes it a popular choice for items that must be single-use by definition; for example, tamper-evident seals only work when they cannot be returned to their original state (Johnston, 2003). Plastic seals are typically small, not labelled and not often used in large volumes so are difficult to identify or sort for recycling. Similarly, blister packs are the most popular way to package pharmaceutical products in Europe and are gaining popularity in the USA (Pilchik, 2000). As a mixture of plastic and foil, blister packs are difficult to recycle (Marsh & Bugusu, 2007). Efforts to comply with environmental standards may be making it easier to incinerate blister packs without releasing toxic air pollutants or to recover the foil from the packs (Pilchik, 2000), but these have not yet common. Consequently, blister packs, seals and similar plastic packaging components are often excluded from recycling programmes. Again, the material properties of plastic make it useful and cost-effective for packaging also contribute to a deliberately linear lifepath for those packages.

Beyond the deliberate choice to use of single-use plastics in contexts where they cannot be or are very unlikely to be recycled, plastic is also a popular choice for many durable goods because plastic can be inexpensively created in a nearly infinite combinations of colour, texture, transparency, rigidity and other visual effects. As a result, plastic is used in the manufacture of automobile parts, clothes, toys, electronics, home wares, and many other small elements of modern life. These plastics are multi-use, rather than single-use, and can be used by more than one consumer if well cared for but do not have an infinite lifespan. Ultimately, these plastics are often very difficult to recycle if they had become contaminated during use, if their construction involved multiple or inseparable materials, and if their varied lifepaths means they do not accumulate in large volumes (Subramanian, 2000). As a result, many of these plastics are excluded from recycling programmes, although pilot projects to improve their recyclability may yet lead to viable methods (Subramanian, 2000).

3.2 Linear by accident

Many modern products and packages, whether intended to be single-use or not, are made from plastic with the (stated) expectation that those products will be recycled. These items are often accompanied by a label or decal encouraging users to recycle the item and the item may feature in the symbols, promotional materials or labels used by recycling campaigns. Unfortunately, the provision of recycling collection points does not always match up to the way these items are intended to be used or are actually used in everyday practice. As a result, many plastic products are sent to landfill or left to accumulate in the environment, making them linear-by-accident.

A clear example is the plastic bottles in which manufactured drinks are increasingly sold (Lange & Wyser, 2003). Some users will occasionally refill a bottle with water, but ostensibly plastic drink bottles are intended to be single-use only. At the same time, plastic bottles are the prototypical symbol used to indicate a separated

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'plastic recycling bin'. Plastic bottles are even such popular targets for post-consumer plastic recycling that they are sometimes the only plastic accepted in municipal kerbside recycling collection (Manchester City Council, n.d.). Despite this, many plastic bottles reach the end of their use by the consumer while that consumer is away from home, meaning there may not be an option to put them into a separated recycling bin and so will end up in a linear lifepath rather than the circular lifecycle intended for them.

Unlike plastic bottles, cigarette butts are not usually labelled with messages that encourage users to recycle them, nor are they often specifically collected for recycling even though they can be recycled (Kadir & Mohajerani, 2011). Nevertheless, cigarette butts often end up as litter (Patel, Thomson, & Wilson, 2013) even though they are durable and potentially toxic and hazardous waste. It is not clear if cigarette manufacturers' intended for butts to be as durable or linear as they are, but improper disposal means that butts are almost certainly more problematic than intended. Contentious consumers might be willing to carry an empty bottle to a recycling bin, but it seems few smokers will carry a cigarette butt to a bin, even when that bin is visibly nearby (Patel et al., 2013), much less to a cigarette butt recycling point which is very rare. The real world properties of a used cigarette butt make it apparently worthless and disgusting, which makes people want to get rid of it quickly. Thus, proper disposal must be extremely convenient to stand any chance of effectively keeping butts in a circular lifepath.

Another issue is when plastic is used in the production or packaging of health and beauty products, such as ear buds, wet wipes, menstrual products, condoms and more. As with cigarette butts, once these items are used, they become apparently worthless and/or disgusting so users will be eager to dispose of them quickly. The places that these items are most frequently used means that they are more likely than many other plastic items to be flushed into the sewer system. However, the sewers systems are not well equipped to capture or separate out plastic waste for recycling. More worryingly, sewer systems are not even well equipped to prevent plastic waste from simply being dumped into the environment where it can accumulate and cause diverse problems. The plastic used in these items may or may not be intended to be recycled, but it is clear that the way these items are used in the real world makes them less likely to be captured at all creating not only a linear lifepath but a particularly damaging linear lifepath.

3.3 Linear by both accident and design

There are, of course, many plastic items that are linear as a consequence of both accident and design. Crisp packets, for example, are designed to be a single-use plastic and are also not (yet) recyclable. At best, plastic crisp packets will be captured in general waste streams for incineration or landfilling. At the same time, crisp packets are used by people and in contexts in which they are not consistently placed in general waste bins and, even when binned correctly, are lightweight enough to be accidentally removed from a bin and lost to the environment. As a result, crisp packets are a common example of the particularly problematic plastics that cannot be recycled or reused but also tend to accumulate in the environment and cause serious damage. Other common offenders include tampon applicators, drinking straws, cotton ear buds, plastic bags, fast food containers and bottle caps.

4 Framework for introducing circularity

The material properties of plastic combine with choices made along the creation, use, disposal and management ofplastic to create linear lifepaths rather than circular lifecycles. There are multiple ways to change these choices that would increase the circularity of plastic; the 5 R's (Refuse, Reduce, Reuse, Repurpose, and Recycle) are well known and catchy, but it is not clear that this is complete nor is it clear how the different options related to each other in terms of contribution to circularity and whether they are an appropriate solution in all contexts. Consequently, this section introduces six methods for increasing circularity, discusses their pros and cons, and highlights some issues where a given method is more or less suitable for certain situations. This section also introduces the concepts of how the various methods might interact in both positive and negative ways, which is important if multiple methods are combined in order to deal with diverse contexts in a mutually reinforcing way.

4.1 Recycle

Recycling is theoretically the best way to deal with existing plastic waste and, theoretically, almost all plastic is re- cyclable. Post-industrial plastic is relatively easy to recycle because it is relatively uniform, comes in large volumes, and has been used in a single or small number of contexts that require only straightforward processing. In contrast, post-consumer plastic recycling is difficult because it typically a mixture of many different kinds of plastic in smaller volumes, and has been used in many ways that require a great deal of complex processing. Post-consumer recycling processes are typically part of municipal waste management, which means that they must competes with other services for limited local government budgets. The post-consumer processing involves sorting, cleaning and processing that is complicated by the variety of plastics used by consumers, the way consumer plastics materials are often mixed, poor labelling, contamination, low volumes and unclear responsibilities and incentives. As a consequence, the majority of plastic waste from western countries has, at least until recently, been sent to other countries where it was assumed that recycling was economical as a consequence of lower labour costs; unfortunately, plastic sent for recycling abroad may be processed in low-tech ways without environmental controls, incinerated, sent to landfill, or dumped (Gourmelon, 2015).

4.2 Avert

Like many other plastic items, food packaging can be made of paper, metal, glass, and plastic as well as combinations of these (Marsh & Bugusu, 2007). Plastic has some clear advantages for hygienic preservation (Ščetar, Kurek, & Galić, 2010) and the low weight of plastic makes it economically advantageous for high volume central production and later distribution (Marsh & Bugusu, 2007). Importantly, central production and subsequent distribution is economically beneficial when the costs of plastic waste management not born by the producers but might not be were the costs of collecting, sorting, cleaning, and recycling plastic waste to become the responsibility of producers.

Individual consumers are increasingly encouraged to consider avoiding single-use plastic, such as plastic straws (Boffey, 2018), even though they may not have control over the choices (e.g. if presented with a drink that alreadyhas a plastic straw in it). Banning such single-use plastic items is an appealingly simple solution, but does not allow for cases in which crucial problems are currently best solved by single-use plastics. For example, people with some disabilities find that plastic straws are an essential survival tool, not just a luxury or choice (Wong, 2019). Consequently, averting plastic depends on the availability and accessibility of effective choices

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that meet individual needs.

4.3 Minimise

Another option to increase the circularity of plastic is to minimise the quantity of (virgin) plastic used in a given product. In a competitive market, producers will typically try to reduce costs by minimising materials used, either for the product itself or its packaging (Hopewell, Dvorak, & Kosior, 2009). For example, cleaning products or cosmetics may be sold in minimal plastic 'refill' packs to be used with more plastic intensive and durable standard packs. Further, cost-conscious producers are likely to quickly adopt any innovative reductions methods.

Unfortunately, not all markets compete on price. Luxury products, or those aimed at status, that are meant to be displayed or that are associated with prestige will seek to maximise the appeal or exclusivity of their products and may seek to maximise the plastic used in a product or its package (Hopewell et al., 2009). Fewer mechanisms will minimise the use of plastic in cases where producers are not competing on price, although prestige, appeal or exclusivity could potentially target the use of recycled plastic in place of virgin plastic.

4.4 Simplify

Post-consumer plastic is currently hampered by the intensive effort needed to sort, separate and pre-process plastic as a consequence of the way that plastics are mixed within a single product or package. For example, the drinks bottles that are so often targeted for recycling often contain multiple types of plastic in the bottle itself, the cap and safety seal, and the label, each of which takes advantage of the distinct material properties of different plastics and plastic formulations. Each must also be isolated in order to be processed differently in unique recycling paths. Similarly, one or more types of plastic may be mixed, or even fused with, other materials such as paper, card, metal, glass or fabric. Take-away coffee cups are a commonly recognised example of a paper-plastic blend that is difficult to recycle because of how complicated it is to separate the mixed materials.

It would seem that one way to increase plastic recycling, and thereby increase the circularity of plastic lifecycles, would be to simplify the number, types or mixtures of plastics used for consumer products or packages. Although competitive market forces do not obviously encourage producers to simplify their products to make them more circular, there are some examples including innovations in graveyard candles in Slovenia (Sanz et al., 2010). More widely, new voluntary or obligatory production standards relating to plastic material simplicity might be forthcoming were the cost of plastic waste management to be the responsibility of producers.

4.5 Delay

Items made from plastic can be used many times and kept for long periods of time, but the low cost and colourful potential of plastic make it appealing for items that are purchased, used briefly and then disposed of in rapid turnover consumer fashions or trends. When this relates to textiles it is called 'fast fashion' or 'disposable fashion' (Morgan & Birtwistle, 2009), but it also applies to fast-churning consumer items like personal electronics, sports equipment, or housewares. Producers of fast fashion tend to focus on aesthetic, constant design change, immediate product availability and low price at the expense of product quality or durability, which then encourages yet more rapid turnover and 'faster' fashion. In response, 'slow fashion' encourages the purchase of fewer and higher quality things (Morgan & Birtwistle, 2009), typically 'timeless' classic pieces or vintage items with demonstrated quality. Cost-conscious options include repairing items, buying second-hand, 'swapping', and otherwise thrifty consumerism practices (Holmes, 2019) or creative adaptation and re-purposing products or materials in new ways. Similarly, individuals are increasingly being encouraged to carry reusable and high quality water bottles, coffee cups, cutlery, and other personal items because they are environmentally responsible but also because they are beautiful, comfortable to use, and attractive.

Unfortunately, fashion (and especially fast fashion) is often marketed at young people who may prioritise being on trend over owning long-lasting high quality items, secondhand items, or artisan made items. A link between quality and price also means that not all consumers are in a position to invest in long-term pieces. At the same time, the durable and reusable water bottles, coffee cups, and other items individuals are encouraged to carry may be disposed of or replaced faster than necessary because they too are subject to fashion trends. Essentially, consumer behaviour may be very difficult to influence on its own because consumer choices are made in complex contexts.

4.6 Recover

Some methods of chemical processing turn plastic waste into input materials for useful chemical processes, and when this is used to create new plastics it is easy to understand as recycling (Al-Salem et al., 2009). At the same time, when these chemical processes turn plastic waste into petrochemical fuels (Al-Salem et al., 2009) they are perhaps better understood as energy recovery. Chemical energy recovery is thus not dissimilar to energy recovery from incineration; both increase the circularity of plastic by re-purposing some of the resources used in creating the plastic and by saving the energy and resources needed to manage plastic waste in landfill. Energy recovery is less circular than recycling, and care must be taken to avoid producing harmful outputs from the energy recovery process such as air pollution, but as it is one of the most widespread was of increasing circularity of plastic waste.

More recently, some strains of bacteria have been discovered that are capable of eating plastic films and, in the process, releasing water-soluble outputs (Yang, Yang, Wu, Zhao, & Jiang, 2014). It is not yet clear whether such microbial consumption is a viable way to dispose of currently problematic volumes and types of plastic waste, nor whether the outputs of such consumption are useful or dangerous in any way. Nevertheless, microbial consumption could potentially be a new way to recover energy or value from plastic waste.

4.7 Combinations, interactions, conflicting pressures

None of these methods of improving plastic waste lifecycle circularity are applicable to all possible plastic waste situa- tions and none are completely free of problems. Each method has strengths and weaknesses which makes them more or less suitable for the different plastics problems. For example, recycling is the most circular option for existing plastic waste, but is expensive and complicated to operate at effective scales and may not be suitable for plastic wastes that are potentially hazardous or contaminated. Averting, minimisation and simplification are ways to make future items more circular by using less (non-recyclable) plastic, but they have nothing to say about existing plastic waste, nor are they necessarily appropriate for all the contexts in which plastic is currently used. Delaying plastic is complicated; it involves complex market forces and consumer

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preferences and may even lead to greater use of (non-recyclable) plastic if reusable plastic items are not actually reused. Moreover, delaying is not suitable for instances of plastic that are only advantageous when not reused. Finally, recovery is cheap and easy but is less circular than recycling and also carries certain risks of air pollution or contamination.

Moreover, each method is more or less suited to being combined with others. For example, all plastic is potentially recyclable but very few ways to recycle plastic return an output that is of equal value to the input, meaning that plastic cannot usually be recycled multiple times. This is especially true for post-consumer plastics which are more likely to be difficult to identify, separate, sort, clean and process in economically viable volumes. Thus, simplifying the types and mixtures of plastic used in consumer products or packages would have a positive interaction with recycling by streamlining the recycling processes, making them more economic rewarding and potentially even improving the number of times that plastic can be put through recycling processes. At the same time, recycling would not benefit from averting or minimising plastic waste as there would reduce the volumes that make recycling economically viable. Recycling and recovery have a more complex interaction. If recycling and recovery were co-located, then plastic wastes could be prioritised for recycling and directed toward recovery only if appropriate. However, if energy becomes much more expensive than recycled plastic as an output, recycling and recovery would compete for priority over plastic waste as an input and so could potentially have a negative interaction.

While simplifying complements recycling, it would seem to be irrelevant to energy recovery. Delaying and avert- ing can work together to reduce the number and speed of plastic items sent for disposal, but delaying is at odds with minimising as durability is not compatible with also being thinner, lighter weight and potentially flimsier. Delaying may or may not clash with simplification, depending on whether or not durable consumer goods require specialised, complex or mixed plastics and materials and with recycling. Likewise, delaying may or may not clash with recycling, depending on whether or not durable consumer goods can or cannot be processed under current recycling methods. Other combinations are not clear as to whether they have positive or negative interactions or even if they have interac- tions. For example, it is not clear if minimisation or averting helps, hinders or has no interaction with simplification. The interactions between the different methods, both positive and negative, as well as the different contexts in which some methods are preferable or more appropriate justify the combination of multiple simultaneous efforts to to increase the circularity of plastic.

Table 1: Combinations are indicated by + to mean potentially complimentary, a - to mean potentially conflicting, and+/- if both are possible. Combinations are also marked as unclear or unlikely as appropriate.

	Recycle	Avert	Minimise	Simplify	Delay	Recover
Recycle	N/A	-	-	+	unclear	+/-
Avert	-	N/A	+	unlikely	+	unlikely
Minimise	-	+	N/A	unlikely	-	-
Simplify	+	unlikely	unlikely	N/A	+/-	unlikely
Delay	unclear	+	-	+/-	N/A	+
Recover	+/-	unlikely	-	unlikely	+	N/A

5 Conclusions

The pros and cons of each of the above methods, as well as the circumstances in which a given method is or is not appropriate, means that there is no single method that will turn all linear plastic lifepaths into circular plastic lifecycles. Moreover, there are some instances when more than one method might be useful but not all of the methods are equal in terms of how much circularity is introduced. However, a multiple, diversified strategy that uses most or all of these methods can significantly increase the circularity of plastic. Before any of these solutions, or combinations of solutions, can have a widespread impact on the problem of plastic waste, there are a few requisite issues to address.

Maintaining the circular plastic lifecycles demands a widespread will to change the way plastic is understood, used, discarded and managed. First, this means changing how plastic is treated as an input. All of the decision-makers that can influence the creation of plastic products or packages, including but not limited to regulators, producers, and scientific researchers, would need to choose circular plastic lifecycles instead of linear lifepaths. For example, producers may choose paper packaging instead of plastic where possible, consumers might boycott products that use unnecessary plastic packaging, or necessary plastic can be made from recycled materials. Second, this means changing how plastic is treated as an output. All the decision-makers that can influence what happens to existing plastic, including but not limited to supply chain members, consumers, waste managers and policy-makers, would need to choose circular plastic lifestyles instead of linear lifepaths. For example, consumers can learn about and follow proper plastic waste disposal, public spaces can be equipped with more opportunities for recycling bins, and waste managers can invest in technology or expanded teams to improve the separation, sorting and processing of plastic waste. Some actors can influence how plastic is treated as both an input and an output, but other actors can only influence one or the other, so actors may have diverse and potentially conflicting goals and incentives.

A multiple and diversified strategy to increase the circularity of plastic as an input and and output requires change and innovation in diverse arenas. For example, one clear opportunity for change would be legislative; simplification can be improved through new requirements for labelling, recycling can be boosted by ambitious targets for recycling rates, and averting can be supported by rules about minimum recycled plastic content. Another popular opportunity is technological innovations; recycling would benefit from improved mechanical tools for sorting, cleaning, and pro-cessing plastics or even from new methods for collecting micro-plastics from contaminated environments. Similarly, research innovations may improve recovery or recycling by identifying new microbes that consume plastic, improving the scales at which plastic can be metabolised, or by finding valuable uses for the outputs of microbial action. So- cial innovations could support several methods through increased consumer demand for recycled plastic or plastic-free products or could improve recycling by creating new norms around proper disposal.

None of these changes would be easy. Production, distribution, consumption and disposal of plastic has developed without any clear assignation of responsibility for maintaining the circularity of plastic. As no one is clearly responsible for maintaining plastic circularity, there are almost certain to be disagreements over who should take up the burden of that responsibility. These disagreements will be complicated by the power imbalance between vocal special interests and the less vocal public or environmental interest. For example,

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legislation changes could seek to make a greater number of producers responsible by expanding the take-back and disposal schemes that currently apply to the automotive or electronics industries. Producers are likely to argue that this could drive them out of business while also arguing that consumers are responsible for creating a demand for recycled plastic, plastic-free or otherwise circular products and packages. As waste collection is often coordinated locally, national governments may try to push responsibility onto local governments. Those local governments are likely to claim insufficient funding but they may also seek to assign responsibility to residents by penalising poor plastic separation within municipal waste collection systems in the absence of other changes.

In conclusion, the solving the problem of linear plastic lifepaths seems to demand a mix of several methods, ranging from the fairly obvious (recycling) to the less obvious (simplification). At the same time, enacting a mix of methods for increasing plastic circularity relies on a mix of legislative, technological, scientific, social and even economic innova- tions that work together to change how plastic is treated as both an input and an output. Thus, dealing with plastic waste will rely on mutually reinforcing changes in several different social arenas, each aiming at different actors, contexts, methods and mechanisms. It is important that the combination of methods, and the weight given to each, in a diverse strategy must assign responsibility to those who have real power to improve the circularity of plastic over its entire production, distribution, consumption and disposal or re-use lifecycle. This coordinated change will be most effective if the burden of responsibility is accompanied by meaningful incentives in a supportive context.

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Stay in the loop: the role of indicators in supporting decisions for circular economy strategies aiming at extending products life

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Abstract
Circular economy proposes an innovative "circular" model towards increased sustainability. The central tenet of circular economy is to move away from linear practices ("take-make-use-dispose" approaches) towards the continuous "cycling" of products, materials and resources. Circular economy can be achieved by adopting practices that include solutions for a) intensified use of products (e.g. product pooling and sharing); b) circular product design (dematerialised products; designed for longevity, reparability and recycling); c) material and resource "cycling", and more. Along with radical transformation of business models and value chains, product design is of the essence to effectively support circular economy transitions. The EEA report "Circular by design" from 2017 on products in the circular economy highlights that designing products using clean materials or increasing use of modular design is "a prerequisite for circularity". Design stage, therefore, is crucial in "initiating" circular shifts; however, the strategies that aim at extending life cycles of products that are currently on the market are as significant. The European Commission made a resolution on a longer lifetime for products (2016/2272(INI)) stressing the urge for extended producer responsibility to tackle the issues of durability, reparability and recyclability of tangible consumer goods.

This article aims to provide an insight on how the sustainability related performance indicators can support decision making for circular economy strategies aiming at extending life time of existing products, components and materials (through service, repair and recycling) taking a cross-business process view. The article provides an example of indicators and their application to a hypothetical case study. We follow the indicator selection procedure, with the help of which the set of relevant indicators is selected for the CE initiative assessment. By taking a case example, we demonstrate i) the importance of operating with indicators across business processes; and ii) the importance of a dynamic indicator set (as opposed to the 'prescribed' indicators). Based on the final performance indicator set relevant for the case, the decision can be made to either implement the strategy, select/combine with another or avoid the implementation altogether.

Keywords: Circular Economy, Extending Life Cycle, Performance Indicators, Decision Making for Sustainability

1. Introduction

Products play a key role in the European economy, providing the service and functions to the society to satisfy their needs. It is reported that worldwide two-thirds of the adults use the Internet, in Africa and South Asia a smartphone being a main device to provide such access (Poushter and Stewart, 2016). Mobile technologies and services generated 3.3% of GDP in Europe alone, serving around half a billion of mobile subscribers (GSMA, 2017). Despite the economic and social benefits products and services bring, products and down- and upstream activities associated with them, such as raw material extraction, production, distribution and use, and disposal contribute to other global and local environmental pressures, such as resource depletion, air, water and soil pollution, waste generation (OECD, 2003). For instance, the mobile phone system consumes annually approximately 2200 GWh of electricity in Italy, which is equal to around 1% of the national electricity consumption (Paiano et al., 2013). The growth in gross national income per capita in Europe has also been correlated to an increasing municipal solid waste generation (Geyer et al., 2017), which for some European countries (e.g. Denmark, Greece, Malta) more than doubled from 1995 to 2017 (Eurostat, 2017). This challenge can be overcome by adopting a circular economy (CE) model, in which the value of products, materials and resources is maintained for as long as possible, consequently contributing to a low-carbon and low waste economy (European Commission, 2015). In this context, designing products that are durable, repairable and recyclable is crucial for the development of CE. Large body of the literature (McAloone and Pigosso, 2018; Nielsen and Wenzel, 2002) conclusively states that the design stage plays a key role in influencing the product's environmental impact during its whole lifetime. By adopting eco-design principles, the manufacturing industries will be able to improve the environmental performance of the products without compromising the costs, quality and performance (Issa et al., 2015); furthermore, eco-design can stimulate transition to CE by providing guidance on the design of products for reparability, durability, upgradability and recyclability (European Commission, 2015).

Despite eco-design being recognized as one of the promising management approaches for environmental sustainability (Fernandes et al., 2017), several studies, focusing on product design for CE (den Hollander et al., 2017; Moreno et al., 2016), have argued that eco-design may not be sufficient as a sole approach to address the complexity of aspects product design for CE should be based on. In their interpretation, product design for CE should extensively take into consideration human-related aspects as opposed to a technical perspective, which is dominant in eco-design approach (Bhamra et al., 2011). The argument is stipulated by a discussion of the premature product obsolescence, which product designer can influence by considering both, the technical (physical) durability and the emotional durability,
i.e. the durability that occurs when the product is designed to induce attachment of a user to it (den Hollander et al., 2017). Indeed, as Prakash et al., 2016 (in (European Environment Agency, 2017) found, in Germany in years 2012- 2013, "30 % of white goods purchased replaced an appliance that was still functioning — the decision to buy a new product was motivated solely by the consumer's desire for an upgrade". For clothing, the desire of a consumer to purchase a new item has been linked to a relatively low price to acquire an item and 'fast fashion' cycles (EMF, 2017).

Furthermore, the myopic, solely product design, perspective, is not enough to obtain the benefits the CE is

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projected to achieve (Bocken et al., 2016).

Circular economy implies a systems perspective, where production and consumption systems both need to be redesigned to function in a circular way; for the manufacturing industry, accordingly, it requires introducing simultaneous changes in multiply business process, including business models, forward and reverse logistics, manufacturing, product design and development and others (Lieder and Rashid, 2016). To guide the manufacturing companies in transition to CE, (Pieroni et al., 2019) developed a configurator for opportunities and designing business model concepts for circular economy; (Van den Berg and Bakker, 2015) proposed guidelines for product design in circular economy; while other authors suggest a more synergetic development, like a product and business model design framework for circular economy (Bocken et al., 2016), a framework to integrate circular business models and circular supply chain management (Geissdoerfer et al., 2018), etc. Despite a wider recognition to address synergetic development of products with business models and value chains for CE (see more by (den Hollander et al., 2017; Moreno et al., 2016), there is a lack of methods to assist manufacturing companies in providing a comprehensive support in doing so (Pieroni et al., 2018). Such support is needed to ensure that the circular 'goodness', embedded in the product, is harvested for environmental and economic benefits of the company's business ecosystem. For instance, for a product, designed to be remanufacturable, a system has to be set up to allow the products to flow back to the focal (controlling the value chain and the brand) company to be remanufactured, thus requiring a new business model and reverse operations system to be designed accordingly. For the company, therefore, there is a strong potential to systematically capture and retain the economic value of the product over time (den Hollander et al., 2017). This is particularly essential in order to realize the European Commission's resolution on a longer lifetime for products (2016/2272(INI)), which stresses the urge for extended producer responsibility (EPR) to tackle the issues of durability, reparability and recyclability of tangible consumer goods. Although the EPR legislation, which requires producers to take responsibility for their product after post-consumer stage of a product's life-cycle, is intended to provide incentives for producers to design products for easier disassembly and recycling, several studies point out at its limited effectiveness on incentivizing the extension of product's life through repair and remanufacture (Kunz et al., 2018). EPR has had most influence on waste collection and recycling (partially because of setting targets for recycling), but not on incentivizing repair or remanufacturing (due to the lack of targets and indicators for repair, reuse, remanufacturing) (European Environment Agency, 2017; Kunz et al., 2018). Furthermore, some authors (Huang et al., 2019) argue that EPR can (unintentionally) have counterintuitive design implications for durable products, stating that "stringent recycling targets incentivize producers to design for durability, yet this may come at the expense of product recyclability. In contrast, stringent collection targets incentivize producers to design for recyclability, yet this may come at the expense of durability" (p. 2574). These regulations, and, consequently, design choices, can hinder realisation of circular economy strategies and impact their sustainability performance (Kunz et al., 2018). CE impact on sustainability performance should be measured prior, during and after CE Considering the complexity of decisions the manufacturing companies need to take to design their products and business models for CE, and the importance of these decisions to incorporate sustainability considerations and be supported by sustainability measurements, we provide a study on the deployment of a set of tools to support selection of relevant leading sustainability-related indicators for measuring potential sustainability performance of the CE strategies that aim at extending products life (such as repair and maintenance and recycle). We follow the indicator selection procedure, with the help of which the set of relevant indicators is selected for the CE initiative assessment. By taking a case example, we demonstrate i) the importance of operating with indicators across business processes; ii) and the importance of a dynamic indicator set (as opposed to the 'prescribed' indicators).

2. Methods

The section provides on overview of the conceptual framing – a tool and a procedure developed in earlier research stages to support quantitative sustainability assessment of CE initiatives. We then proceed to presenting a case company, which help us demonstrate the applicability of the selected tools.

2.1 Leading sustainability performance indicator database and the selection procedure

The Leading sustainability performance indicator database comprises a repository of 270+ leading performance indicators that are classified according to three major elements: organizational business processes, CE strategies, and TBL dimensions and aspects (Figure 1, (a)). For the CE strategies layer, a list of strategies have been compiled and elaborated on from the CE framework by (Potting et al., 2017). This framework has been selected based on its inclusion of a wide range of CE strategies relevant for the manufacturing context (not sector-specific) and provision of definitions of these strategies. The list consisted of thirteen CE strategies, which range from dematerialisation and product-service system strategies through recycling and recovery. For the business process layer, five major business processes have been considered: business model, product development, production & operations, after-sales service, and end of life operations. These processes are typical for any manufacturing company (Ray et al., 2004). The business process layer allows to retrieve indicators relevant to measure during business processes affected by the CE strategies in focus. This construct enables an integrated consideration of CE strategies across various business processes. For the sustainability layer, three dimensions from the TBL view were considered (environmental, economic and social), with multiply aspects covering each dimension. As a result of the indicator collection and classification (described in detail in paper by Kravchenko et al. (2019a, in review for JCLP), each CE strategy is covered by a range of leading performance indicators, which can be used to analyse the potential economic, social and environmental performance. The consolidated database of leading sustainability-related performance indicators provides industrial practitioners, who express their interest in understanding the sustainability considerations and implications of circular economy initiatives by means of employing quantitative sustainability indicators, with a systematized repository, which reveals what indicators are relevant to measure for each CE configuration (i.e. a combination of a CE strategy/ies and a business process) (Figure 1, (b)), as well as what dimension of sustainability the performance is being measured (Kravchenko et al., 2019). Figure 1 shows the abstract representation of the 'Leading performance indicator database'layout: (a) classification criteria for leading performance indicators; (b) a set of N number suitable indicators available for the selected CE configuration i (a combination of CE 'reduce impacts in raw material and sourcing', CE 'reduce impacts in manufacturing' and a business process 'production & operations'). A database is accessible in an Excel format at the web-address https://doi.org/10.11583/DTU.8034188.v1

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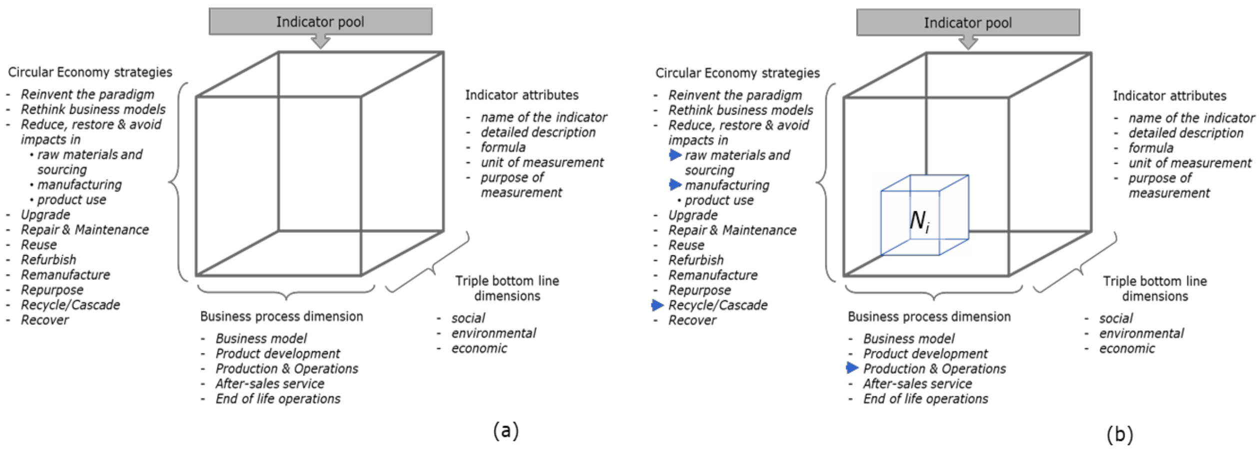

Figure 1*. The abstract representation of the 'Leading performance indicator database' layout (a) and indicator selection logic (b).*

In order to select a set of suitable indicators for the case presented in this research, the indicator selection procedure was followed. The indicator selection procedure has been developed to assist an industrial practitioner in a meaningful selection of suitable indicators available from the indicator database (Kravchenko et al., 2019b, in review). The procedure takes into consideration the complex nature of circular economy by allowing the user a dynamic selection of indicators based on the combinations of multiply circular economy strategies and business processes relevant for the case as well as its contextual settings (product, industry, sustainability aspect of high concern, etc.). The indicator selection procedure has been empirically evaluated through a case study approach, with the final version available in (Kravchenko et al., 2019b, in review) and as presented in Figure 2. To work with the indicator selection procedure, a combination of CE strategies and business processes needs to be defined (Step 1), thus serving as an input to Step 2, where the inputs need to be applied by setting filters in the 'Leading performance indicator database'. As a result, an initial indicator set will be established. Several sub-steps under Step 2 have to be executed to gradually select indicators for the final set (Step 3). For the sub-steps under Step 2, the user team have to comprise the people with substantial knowledge of business processes that are in focus (identified in Step1) and sustainability or environmental managers, who have expertise in working with sustainability projects. Finally, it is important to implement the final set of indicators in order to understand the performance of the selected CE initiatives by comparing them with the baseline situation.

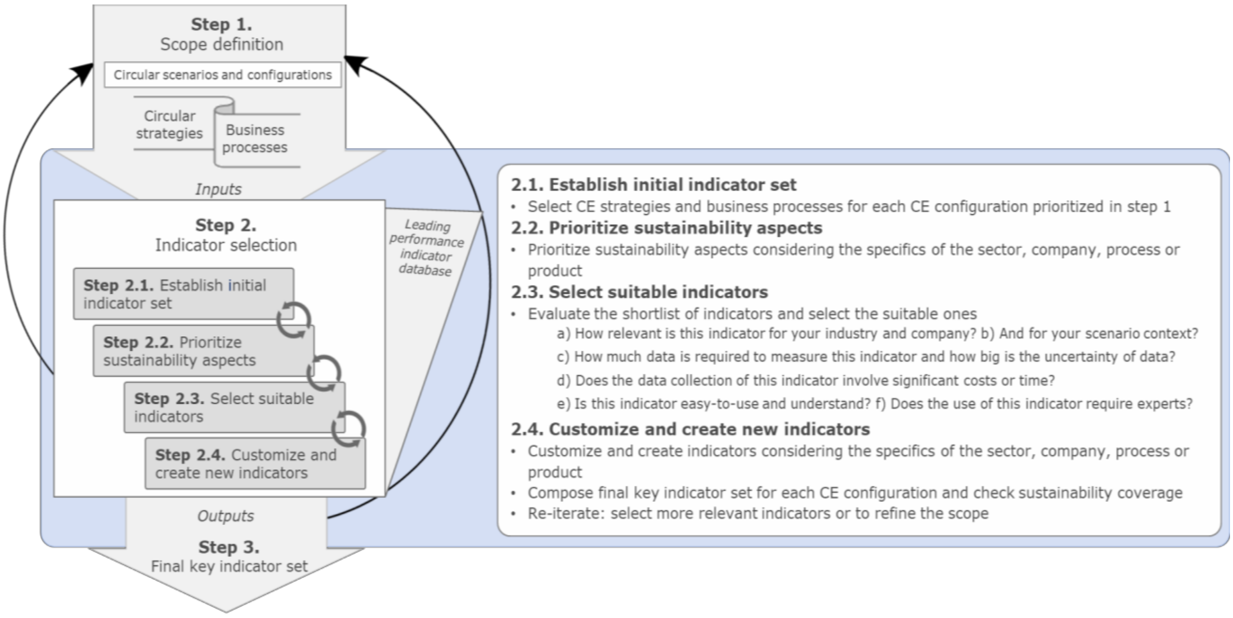

Figure 2. *The procedure for a systematic indicator selection for CE sustainability performance measurement.*

2.2 Case presentation

We present a case, which was set up to be used to retrieve a set of relevant indicators applicable for the CE strategies aiming at extending products life considering an integrated business process approach. The results, consequently, show to what extent the 'contextual' boundaries influences the number and type of indicators to be used to measure the potential sustainability performance of the selected CE strategies. Circular economy is a complex and multifaceted phenomenon (Potting et al., 2017) and a specific case settings allow to have the circular economy phenomenon explored in its 'contextual' boundaries, i.e. how it is being operationalized and measured using sustainability-related indicators.

The case company, CarpetCo, belongs to the manufacturing industry producing carpets for residential buildings, non- residential buildings (business and governments), and transportation service. The carpet manufacturer case was selected for this study due to relative product durability, complexity (variety of materials) and low recycling rates (Wilts et al., 2017), as well as representing the sector of 'uncertain' circularity potential (EMF, 2013; European Commission, 2014). While the global demand for carpets is rising (totalled 4.45 billion square meters in 2014), the most common end of life scenario is still landfilling (60 % in Europe) and incineration (Wilts et al., 2017). This can partially be attributed to the complexity of the product, because of the variety of materials, synthetic and organic fibres and resins that are bonded by adhesives together (Miraftab et al., 1999). This challenge is further aggravated by the fact that carpets need to be maintained during their use, which often requires application of cleaning equipment (e.g. vacuum cleaning and detergents). Considering the challenges, CarpetCo wants to introduce CE initiative to reduce premature product obsolescence and waste generation by considering a CE solution, which comprises the offering through a product-service system, with product support in use and recycling at the end of life (Table 1).

Table 1. *Background information about the case company, CarpetCo.*

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Sector	Customer segment	Current business concept	Circular vision and objectives
Carpet producer	B2B, EU market	'Single' sale of quality carpets, made of three layers: 1st : nylon, 2nd – latex glue, 3rd - polypropylene	Circular vision is to establish a long-term relationship with customers by providing long-life support for their products. Circular objective is to reduce premature product obsolescence, waste generation and increase customer satisfaction. The CE initiative comprises the offering through a product-service system, which includes product leasing, installation, repair and maintenance, and removal at the end of use for recycling.

With this background information, the procedure for a systematic selection of suitable sustainability-related performance indicators for circular economy strategies screening was employed. The Excel database of leading performance indicators was used as a tool to retrieve the initial indicator sets considering the specifics of the case. The indicator database and the procedure are described in subsection 2.1. The indicator database and the procedure were employed internally by a research team acting as a case company representatives.

3 Results and discussion

With the background information on CarpetCo's CE vision, a set of CE configurations have been defined (Figure 3). A CE configuration is a combination of one or several CE strategies and a business process. CE strategies are identified together with the company using a CE strategy framework adopted from Potting et al. (2017). This exercise helped to align what circular solutions the company considers as well as to bring more clarity about what each CE strategy entails. For instance, with the help of definitions provided in conjunction to the framework, CarpetCo's CE solution of developing a PSS was found to belong under CE strategy 'Rethink and reconfigure business models'. In this strategy, the focus is placed on making product use more intensive by rethinking the way of delivering it's function (by selling it's performance or delivering result) and/or value proposition through product leasing, renting, sharing, pooling (Blomsma et al., 2019, in review). By switching to a PSS, CarpetCo's intention is to retain product ownership so the product can be serviced during use, but also retrieved at the end of its use. Using the CE framework, following CE strategies have been identified: 'Rethink and reconfigure business models' (as explained earlier), 'Reduce impact in raw material and sourcing' (because the solution was to use own recycled carpets as a substitute for virgin input), 'Repair and maintenance' (because of the intention to provide cleaning, repair and maintenance service during carpet's use), and 'Recycle' (because carpets would be internally recycled to be used for making new carpets). Business process consideration helped to understand how the identified CE strategies could be operationalized. For instance, a businessmodel has to be redesigned to explain the logic of creating, delivering and capturing value (DaSilva and Trkman, 2014), an 'after-sale service' has to be set up to allow execution of the service planned in the PSS. Furthermore, 'end of life' operations should be organized to manage a product after its removal from the customer at the end of its use cycle (e.g. collection and recycling). From a product design perspective, it may be important to ensure the products is suitable for the proposed CE solution. Therefore, a 'product development' layer can be brought in in conjunction with the prioritized CE strategies ('Repair and maintenance' and 'Recycle') to select indicators to measure how well does the product suit the solution, but also to highlight what has to be measured to (re)design a product to fit the proposed PSS. Following this logic, a set of CE configurations have been set up to identify what indicators are available to measure the potential sustainability performance of the selected CE initiative (Figure 3).

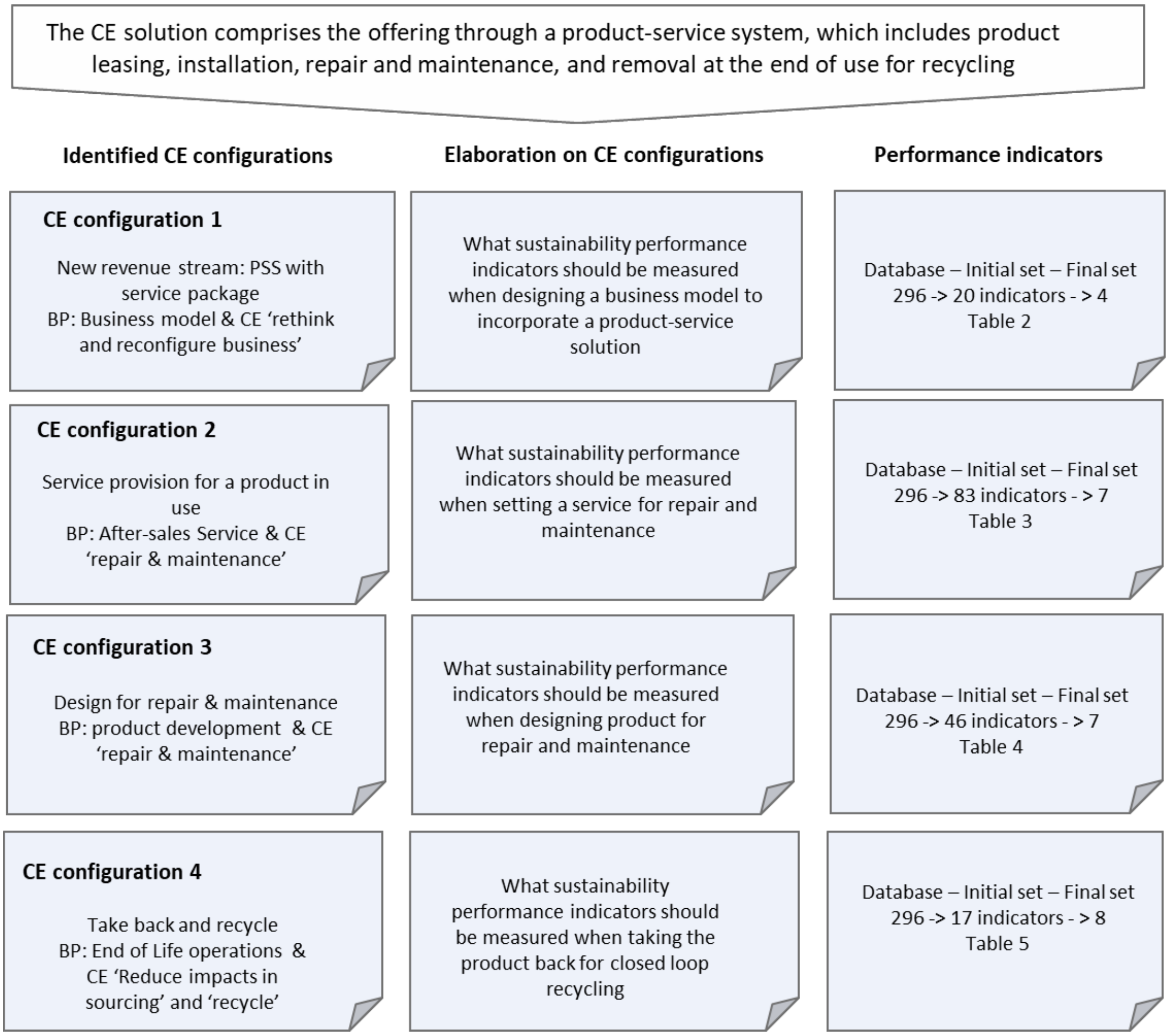

Figure 3. *A set of CE configurations relevant for CarpetCo's CE initiative.*

CE configuration 1 has been defined based on the need to change a business model, with new value proposition to the customer, such as increased product support and maintenance during leasing period and 'care-free' product removal at the end of use. Considering this, an initial set of indicators has been identified (Figure 3), followed by a process of indicator selection for the final set. To select the final indicators, a set off questions were used to guide the process. The questions are listed in Figure 2, under step 2.3. and are as following: a) How relevant is this indicator for your industry and company? b) How relevant is this indicator for your scenario context? c) How much data is required to measure this indicator and how big is the uncertainty of data collection? d) Does the data collection of this indicator involve significant costs or time? e) Is this indicator easy-to-use and understand? f) Does the use of this indicator require experts?. By reviewing the initial indicator set, a final set

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consisted of four indicators. Four key indicators have been selected reflecting the need to understand how the performance will potentially be impacted when changing to product ownership model and providing supporting services. For instance, the indicator 'Product ownership cost in business' has been selected to understand what costs CarpetCo would incur by retaining ownership of leased carpets and providing supportive services. This can potentially signal about the need to re-design a product to ease its installation, maintenance and removal to cut cost of ownership. Furthermore, it was also important to help customer to make the decisions in engaging in leasing, therefore, the indicator 'Product ownership cost for the user' has also been selected. Due to the fact that no environmental indicators could be retrieved for a business model layer (Kravchenko et al., 2019a, in review), a more 'operational' CE configuration, which implied setting a service for repair and maintenance has been used to understand the environmental implications of service provision. The 'Leading sustainability performance indicator database' contains description of indicator attributes that assisted users in understanding each indicator, what is measures and how it is measured (available at web-address https://doi.org/10.11583/DTU.8034188.v1).

Table 2. *A final indicator set for CE configuration 1.*

Nr	Indicator name	CarpetCo comments
1	Product ownership cost in business	Important to determine the direct and indirect costs of offering the PSS scheme (i.e. leasing model with service and maintenance and removal). It can be that the carpet has to be re- designed to ease cleaning and maintenance
2	Maintainable period after sales	A contract duration with a customer is important to establish a long-term relationship
3	Product ownership cost for the user	Important to help customer to make the decisions in engaging in leasing
4	Job creation per unit of product	Important because services associated with product service and maintenance require labour, also close to the user of the product

CE configuration 2 has been defined based on the new business model of product-service system, which implies installation and service provision like cleaning, repair and maintenance. CarpetCo, therefore, was interested in understanding what sustainability performance indicators should be measured when setting a service for repair and maintenance, so to ensure possible changes to the process or product can be introduced prior it is actual implementation. As a result of the indicator review, the final set of performance indicators consisted of 7 indicators (Table 3). Most of the indicators addressed the costs associated with service provision (e.g. labor cost and energy cost), however the costs of water, energy and cleaning agents can directly be linked to resource consumption, therefore, acting as indicators measuring performance on both, economic and environmental aspects (Kravchenko et al., 2019). During the indicator review process, the indicator 'Duration of product use' has been selected by the company to understand how service provision and maintenance can affect the carpet's useful life; in addition, the indicator 'Replaced parts' has been added to the set because the company realized that the carpet may need to be redesigned to allow replacement of some worn out parts instead of replacing the whole carpet. These indicators have been identified important to help understanding how CarpetCo's CE objective to reduce premature product obsolescence can be achieved.

Table 3. *A final indicator set for CE configuration 2. Social indicators have been deselected for this CE configuration, because the company has a control over work and employment conditions.*

Nr	Indicator name	CarpetCo comments
1	Labor cost per unit of service	This indicator measures the cost associated with cleaning and quality check. We need to ensure there is cost effectiveness in service delivery for our product
2	Duration of product use	Important to understand the difference of our product's durable life from the market average
3	Cost of water during use phase of the product	Helps to understand water usage during service provision (e.g. for cleaning)
4	Cost of energy during use phase of the product	Helps to understand energy usage during service provision (e.g. for cleaning)
5	Time for service provision	Important to decrease waiting time for the user by establishing local service points and by training servicemen to provide service
6	Cleaning agents used by service providers	Important to measure amount (type) of cleaning agents for service provision. Decreasing this amount can avoid harm to the environment and decrease costs
7	Replaced parts	Can we replace worn out parts of the carpet without replacing the whole carpet?

CE configuration 3 has been defined following the company's intention to understand what has to be measured when designing a product to be repairable and maintainable, so to understand how well does the product fit into the new business model. Indicators 'Number of modules' and 'Time for worn part replacement' have been found very important as they will define how to design a carpet to ease accessibility of worn parts, thus facilitating the process of their replacement and affecting the cost of repair (Table 4). Because of the 'product development' layer, the indicators 'Amount of Restricted Materials (REACH) in products' and 'Amount of Prohibited Materials (SVHC) in products' have been selected to understand whether any carpet contains these materials, so they can be eliminated to reduce health risks and facilitate recycling at the end of life (so moved to the CE configuration 4). Interestingly, the indicators'Existence of Repair Manual with instructions' and 'Availability of repair kit or spare parts' have been found interesting and added to the list, because they may be important if the company decided to provide a similar type of a product to B2C market, where the customer could be encouraged to 'repair' carpets themselves.

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Table 4. A final indicator set for CE configuration 3. * this indicator has been customized to address the particularity of the process.

Nr	Indicator name	CarpetCo comments
1	Existence of Repair Manual with instructions	Interesting indicator, which can be considered for the future. Making the manual available for the user is important to give the user "right to repair" and possibly encouraging the user to repair the product
2	Availability of repair kit or spare parts	Interesting indicator, which can be considered for the future. Repair kit and spare parts available for the user enable the user to repair the product when necessary. It may encourage the user to repair/replace the parts instead of disposing the whole product
3	Amount of Restricted Materials (REACH) in products	Important to reduce (or eliminate) hazardous/toxic material content in products to minimize health risks and increase potential for open loop recycling
4	Amount of Prohibited Materials (SVHC) in products	Important to reduce (or eliminate) hazardous/toxic material content in products to minimize health risks and increase potential for open loop recycling
5	Number of modules	Modular design facilitates repair, reuse, recycling and remanufacture.
6	Time for worn part replacement*	It's necessary that worn parts are easily accessible and visible, in order to facilitate and economize on the process of their replacement
7	Product Solid Waste Fraction	We need to measure how much product is 'saved' from removal due to our modular design and repair

For CE configuration 4, the question in focus was about what sustainability performance indicators should be measured when taking the product back for closed loop recycling, i.e. recycling the used carpet to be used as an input to produce same product type (therefore, the CE strategy ‘reduce impact in raw material and sourcing’ has been selected together with CE ‘recycle’). As a result, the final set of indicators consisted of eight indicators (Table 5), which mostly covered environmental aspects (indicators nr. 2 to nr. 8). The environmental indicators covered the ‘material’ aspects, thus providing an indication to what extent is the product in its current form suitable for recycling (indicators nr. 3, 4, 5 and 6), and what potential performance of the recycling process could be (indicators nr. 7 and 8). It is interesting to note that the initial indicator set proposes indicators that measure other aspects during recycling, such as ‘Hazardous Solid Waste Mass Fraction’, ‘Hazardous liquid Waste Mass Fraction’, ‘amount of water used for recycling’ and ‘amount of hazardous substances using for recycling’. These indicators would become key indicators if the case company would come from the electronic sector, where recycling of electronics often implies usage of great amounts of energy, water and acids to recover, for instance, rare elements from batteries (Zeng et al., 2014). Indicators nr. 3 and 4, on the other hand, could have been deselected by the company because of their intention to do a closed loop recycling; however, the company decided to make sure their product is free of the restricted materials to avoid contamination in case the recycling is done by another entity (open loop recycling). The indicator 'Take back cost' measures performance on operational costs of product take back system, while the indicator 'Load mode of transport' should provide an indication how much the space capacity of transport is used to transport used product for recycling, thus affecting the fuel consumption and cost of transportation.

Table 5. A final indicator set for CE configuration 4.

Nr	Indicator name	CarpetCo comments
1	Take back cost	This indicator is important to understand the costs associated with a product take back option. Take back collection requires reverse logistic in place
2	Load mode of transport	Important to understand how much the space capacity of transport is used to transport used product for recycling
3	Amount of Restricted Materials (REACH) in products	Important to reduce (or eliminate) hazardous/toxic material content in products to minimize health risks and increase potential for open loop recycling
4	Amount of Prohibited Materials (SVHC) in products	Important to reduce (or eliminate) hazardous/toxic material content in products to minimize health risks and increase potential for open loop recycling
5	Painted, Stained or Pigmented Surfaces	Current usage of glue complicates the separation for recycling
6	Number and type of material in a product	We need to make sure our materials are compatible for recycling
7	Recycled Embodied Energy	Maybe important but difficult to calculate. However, it may be important to measure energy necessary to recycle and produce one kg of the recycled material to be used as an input for our new carpet
8	Waste generated in the recycling process	This indicator measures the waste amount generated in the recycling process.

Figure 4. shows the number of indicators from all final sets per sustainability dimension, which gives an overview of how the dimensions are represented and what aspects are covered (some indicators are cross-dimensional).

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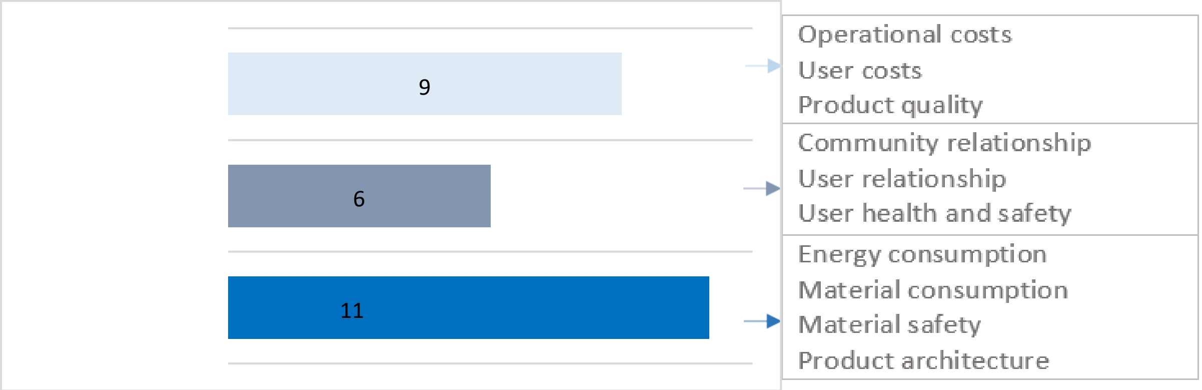

Figure 4. *Number of indicators per sustainability dimension and key aspects covered by selected indicators*.

The final overview of sustainability aspects to be measured by selected performance indicators provides a good understanding to the industrial practitioners about key aspects that are likely to be affected by the described CE initiative (combination of CE configurations). Therefore, this set acts as a proxy of what has to be measured in order to assess potential sustainability performance of the selected CE initiative, which can then be compared to the 'linear' initiative on the basis of the same set. Furthermore, the 'business process' dimension places focus not only on activities (i.e. what is performed or not), but on the interconnectedness of these activities (e.g. how a decision taken during business model development or product development can constrain or enable decisions at, for instance, end of life operations). In order to understand the sustainability performance of the selected CE initiative, the final indicator set has to be calculated (Figure 2, Step 3). For that, data has to be collected and calculated, as provided in the formula column in the corresponding 'Leading performance indicator database' (Section 2.1.). Furthermore, in order to understand the results of the calculated indicators for each CE configuration, it is necessary to collect same type of data for the baseline system, i.e. the current, non-CE, system. For instance, the indicator 'Product Solid Waste Fraction' from CE configuration 3 (Table 4) can help the company to understand whether any waste 'savings' occur because of the repair service; the indicator 'Number and type of material in a product' for CE configuration 4 would help the company to understand whether the current product or the redesigned product is compatible for recycling, if not, the CE strategy can be 'postponed' so the company could investigate materials to be used for the product in order to increase its recyclability (if desired). The responsibility for setting up a data collection plan could be placed on the sustainability or environmental manager, who then establishes a process of collecting data across departments and, by understanding the results of indicator calculation, can influence the decisions on CE implementation. For instance, if the indicator 'Cleaning agents used by service providers' (CE configuration 2) shows that a large portion of cleaning agents are used for carpet cleaning during cleaning services (which in that case would increase cost for CarpetCo spend on cleaning agents during service provision as a part of the PSS), then product development team can be involved to address the design (or choice of materials) to reduce the need for cleaning. These examples show how operating with indicators across business processes can facilitate learning about CE and highlight the importance of leading indicators as early-warning informants of potential consequences of decisions in a company. Furthermore, the dynamic process of indicator selection allows a company to select indicators relevant for its sector, product or process, thus increasing the certainty of operating with relevant indicators, as opposed to using a 'prescribed' set of indicators, which may not reflect the 'reality' of the company (for instance, the indicator 'amount of conflict resources (e.g. tin, tungsten, gold) used in a product' may be

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irrelevant for a company from textile sector, however maybe a very important indicator for an electronics company to ensure their usage of such resources does not come from a conflict zone that may perpetuate violence).

4 Conclusions

A growing body of the literature on CE continues to focus on developing support for manufacturing companies in their transition to CE, ranging from frameworks of CE strategies (EMF, 2013), to business model design (Pieroni et al., 2019) and product design (Moreno et al., 2016) for CE, as well as approaches to measuring performance of CE (Azevedo et al., 2017; Cayzer et al., 2017; Ellen MacArthur Foundation, 2015). Despite the growing evidence that transition to CE would require transformation of multiply organizational business process, there is a lack of tools that can support a manufacturing industry in identifying what has to be measured, how and where, so to support decision making for CE. Furthermore, the complexity is intensified, when companies would like to understand the sustainability performance of CE solutions, they are considering to implement. Studies highlight that 'prescriptive' measures, for instance, available from material flow analysis, or 'prescriptive' indicators such as 'recyclability of the product' may not be sufficient to address the complexity of CE configurations (Agrawal et al., 2012). In regard to increasing recyclability, Goldberg (Goldberg, 2017) raises concerns over circulating materials and products that contain toxic substances (e.g. mercury or brominated flame retardants), thus possessing a risk of perpetually creating and moving contamination in the system, if the materials are entering new cycle through recycling. This calls for creating a better understanding of uses of these toxic substances in products to minimize the risk of systemic exposure, but also to quantitatively assess any CE strategy on its potential sustainability contribution prior its implementation. Quantitative assessments may also support manufacturing companies in realizing the objectives of the EPR legislation.

This study focused on presenting the final indicator set, which can be used to measure the potential sustainability performance of CE initiatives in a manufacturing context. For this, a case company example was set up to show how the selected tools, the indicator database and the indicator selection procedure, developed in earlier studies and described in (Kravchenko et al., 2019; Kravchenko et al, 2019a, in review for JCLP), have been utilized. By taking a case example, we demonstrated i) the importance of operating with indicators across business processes; and ii) the importance of a dynamic indicator set (as opposed to the 'prescribed' indicators). Based on the final performance indicator set relevant for the case, the decision can be made to either implement the strategy, select/combine with another or avoid the implementation altogether.

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Relationship between the product development process, circular economy and remanufacturing

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Abstract

It is estimated that between 60% and 80% of all environmental impacts caused throughout the life cycle of a product are determined in the initial phases of its development process. Although the need for more sustainable production models is a fact, most of the current models still follow a linear process of extraction, transformation and discarding. In a world of finite resources, these models cannot work in the long term and there is evidence that the limit is being reached. The objective of this work is to identify existing methods and tools through which value can be added to the life cycle of a product considering the concepts of the circular economy and its application through remanufacturing processes. The research strategy used to reach the objective was systematic literature review. The methods and tools analyzed focus on the integration of customer needs, environmental requirements and economic considerations, emphasizing the importance of the remanufacturing process to help define the entire product cycle. The information presented here can be used by researchers in their future studies and by industry professionals who can find a guide to allow project engineers to choose, alter or evaluate the different end-of-life strategies of the product, which makes the product development process more interesting for organizations from an economic, social and environmental point of view.

Keywords: Product Development Process, Circular Economy, Remanufacturing Process, Methods and Tools

1. Introduction

The product development process (PDP) is a strategic tool or business process that is formed by a set of activities capable of transforming market and technological information into products / services according to company strategies and meeting market needs, through the creation of goods and information for the production, follow-up and removal of a product from the market in a way that gives value so that the product or service cycle is not a cradle to grave but cradle to cradle (Rozenfeld et al., 2006).

Structuring a process such as the PDP can represent proactive environmental management of the products or services for the company or the user throughout its life cycle that aims to reduce the total environmental impact and make it is easier to close the materials circuit. Based on this statement, adding value to product development while respecting the principles of Circular Economy will add value to the product life cycle through the remanufacturing process, thereby reducing manufacturing costs and reducing the extraction of non-renewable materials and providing nutrients (technical or biological requirements) for other manufacturing processes, thus closing the restorative and regenerative cycle of the product.

Remanufacturing is highlighted by several authors as an effective way to keep products in a closed loop, reducing environmental impacts and manufacturing process costs (Pigosso, 2010; Jensen et al., 2019; Zlamparet et al., 2017).

Therefore, this paper aims to present some product development models focused on the integration of different end-of-life strategies, with special attention to remanufacturing and Circular Economy, given their growing importance in the international scenario to reduce product life cycle impacts, reduce the extraction of non-renewable materials and solid waste.

2. Methods

The technical procedure used for the development of this work was the literature review, so that a theoretical foundation was obtained for the elaboration of the work. The research was developed based on material with primary or secondary source already, such as scientific articles, books, magazines, electronic files, among others. This type of research enables the analysis of a theme under new focus, allowing the creation of innovative conclusions.

The research was divided into two stages. In the first stage, a bibliographic survey was conducted in the Scopus and Web of Science databases using the keywords: product development process, circular economy, remanufacturing and design for remanufacturing. Through the analysis of titles, abstracts and keywords of articles published in these databases, 33 references were selected for the elaboration of this work.

The second stage consisted of analyzing the selected works in order to ensure that the understanding of the relationship between product development process, Circular Economy and Remanufacturing Design was broad and non-restrictive.

Following, the concepts, tools and methods found are presented, aiming to promote a better knowledge about the theme and improvement of ideas, since they expose characteristics and relationships about the studied theme, in order to establish an association between these concepts.

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3. Concepts and definitions

3.1 Product Development Process (PDP)

Product development is considered an increasingly valued business process and applied to companies for competitiveness, mainly because it has increasing rates through the internationalization of markets, increased diversity and variety of products, and a focus on reducing product life cycle in the market. The Product Development Process (PDP) is located at the interface between the company and the market, identifying and even anticipating market needs and proposing solutions (through related product and service projects) that meet such needs. Hence its strategic importance. In addition, the manufacturability of the developed product must be ensured, that is, its ease of production, taking into account cost and quality constraints on production. (Rozenfeld et al., 2006).

Product development process is the business activity that most effectively manages a company's products throughout their lifecycle, from the first idea of a product to the moment it is removed and disposed of the market (De Paula; Mello, 2013; Rozenfeld et al., 2006a; Stark, 2015; Tiwong; Ramingwong, 2018). It's not just about managing one of your products, it's about managing all of your parts individually, even the individual product and the entire product portfolio. At the highest level, PDP's goal is to increase product revenues, reduce product-related costs, maximize the value of the product portfolio and maximize the value of current and future products for customers and shareholders (Stark, 2015).

3.2 Circular Economy

According to Ellen Macarthur Foundation (2013) the circular economy refers to an industrial economy that is restorative by intention; aims to rely on renewable energy; minimises, tracks, and eliminates the use of toxic chemicals; and eradicates waste through careful design.

Prieto-Sandoval et al. (2018) found that the concept of Circular Economy was developed from a multidisciplinary perspective thanks to different approaches to disciplines such as ecology, economics, engineering, design and business and it is characterized by three different levels of research and implementation: Micro, Meso and Macro.

In the Micro Level, companies are focused on their own eco-innovation improvement and development processes. The term eco-innovation defined by Kemp and Pearson (2007) is commonly understood as the production, application or exploitation of a good, service, production process, organizational structure or management/business method that is new to the company or user and that results throughout its life cycle, in a reduction in environmental risk, pollution and negative impacts of resource use (including energy use) over its life cycle compared to relevant alternatives.

In the Meso Level are included companies that belong to an industrial symbiosis that will benefit not only the regional economy but also the environment (Geng et al., 2012). In turn, Macro Level through the development of environmental policies and institutional influence is highly focused on the development of eco-cities, eco-municipalities or ecological provinces.

Circular Economy requires innovations in the way industries produce, consumers use, and legislators legislate. In this way, environmental innovation or eco-innovation have evolved over time as well as Circular Economy. This chronological evolution is due to the increasing complexity and dynamism of the economy and markets (Mejía-Villa, 2016).

Hofstra and Huisingh (2014) distinguish four types of ecological innovations: Exploratory; Restorative; Cyclic and; Regenerative. The first two types of ecological innovation (exploratory and restorative) are associated with an anthropocentric view of the world, human needs are the priority, and the idea of growth comes from the traditional linear economy without regard to the limits on energy consumption (Ehrenfeld, 2000). Exploratory ecological innovations pay little attention to environmental issues, but meet legal requirements and seek cost savings. Eco-restorative innovations tend to develop solutions to the damage done, that is, are corrective innovations. In addition, they are eco-efficient in minimizing resource use and emission

Cyclical and regenerative innovations are the two other types of ecological innovations, they are associated with a recent eco-centric view of the world, in which the ecosphere (portion of the earth comprising the atmosphere, the geosphere, the hydrosphere and the biosphere and all the ecological factors that exert influence on living organisms in it; all the ecosystems on Earth as a whole) become important and humans are part of nature and not its owners (Hofstra and Huisingh, 2014).

Cyclic eco-innovations to a higher degree connect humans and nature with the ecosystem, and also improve systems' ability to close circuits. Regenerative ecological innovations are closely related to the ecosystem's ability to create added value for humans and nature (Hofstra and Huisingh, 2014). As a consequence, humans have to consider the role of their actions, that is, if our needs continue to grow, contribute to the resilience of nature (Yuan et al., 2008).

The linear economic model gives rise to chronically high waste levels and creates dependency between economic development and new virgin material inputs. In a world of finite resources, this model cannot work in the long run, and there are indications that it is reaching its limits (EEA, 2016). In contrast, a Circular Economy is a global economic model that aims to decouple economic growth and development from the consumption of finite resources. It is restorative by design and aims to maintain products, components and materials with maximum utility and value at all times.

Unlike a linear economy, it is about perfecting systems rather than components. This includes careful management of materials that are in the biological and technical cycle, as defined by the Ellen Macarthur Foundation (2013). Thus, in technical cycles, materials are maintained, reused, refurbished, and (as a last resort) recycled. In biological cycles, non-toxic materials are cascaded and eventually returned to the ground, thus restoring natural capital. Life cycle materials should be designed for safe and nutritious / regenerative biosphere return.

Possible ways are being explored worldwide in the transition from Linear to Circular Economy (EC) business models. The material flow of an industrial process in the linear economy is unidirectional, that is, raw materials are transformed into an end product and at the end of their useful life result in disposable waste. In the new concept of Circular Economy, there is the reuse of materials that return to the supply chain valuing and recovering waste, finally decoupling the economic growth from environmental losses (Ghisellini et al., 2016).

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3.3 Remanufacturing

Remanufacturing is a process of bringing used products to a "like new" functional state, rebuilding and replacing their components. The practice has a low profile in world economies, however, studies indicate that it achieves cost savings in the region of 20% to 80%, as well as similar quality to an equivalent "new" product (Ijomah, 2002).

There are different definitions for the term remanufacturing. In the case of the automotive industry, the US Automotive Parts Remanufacturers Association (APRA) defines remanufacturing as the restoration process of worn out and discarded durable products to a new condition: “a properly “rebuilt” automotive part is the functional equivalent of a new part and is virtually indistinguishable from a new part”, and clarifies that terms “rebuilt” and “remanufactured” can be used interchangeably and mean the same thing.

APRA also claims that the remanufacturing industry helps the environment in many different ways:

- Energy Conservation: Automotive and truck parts are kept out of the remelting process longer due to remanufacturing. As a result, millions of barrels of oil or comparable forms of energy are saved.
- Conservation of Raw Material: Remanufacturing gives the product numerous lives rather than just one, thus saving raw materials. Remanufacturers annually save millions of tons of natural resources such as iron, aluminum, copper, etc.
- Landfill Conservation: Landfills are spared from dumping millions of tons of iron, aluminum, copper, etc., due to the monetary value that the industry attaches to the parties. This “center load” ensures that parts are returned for reconditioning.
- Air Pollution Reduction: Again, keeping parts out of the cooling process benefits the environment by reducing air pollution that is generated by reflow.

The remanufacturing process includes screening, inspection, disassembly, cleaning, reprocessing and reassembly, and parts that cannot be returned to original quality are replaced, meaning that the final remanufactured product will be a combination of new and reused parts. Increasing the life cycle of a product through remanufacturing can make a profit when that remanufactured product is subsequently sold.

From the consideration of the different factors involved, it can be concluded that remanufacturing may be the best strategy. This is because it allows the embodied energy of virgin production to be maintained, preserves the intrinsic "added value" of the product to the manufacturer and allows the resulting products to be sold "as new" with updated features if necessary. Remanufactured good in relation to end-of-life strategies will be superior to a repaired or refurbished good because the end result of a remanufactured good will also have a higher quality, making it more commercially viable. (King et al., 2006).

3.4 Design for Remanufacturing

Design for remanufacturing (DfRem) is not such a "new" and "unknown" subject as it was for those who studied it in the mid-1990s, as these researchers provided a foundation on which to build further studies detailed and specialized. However, on closer inspection, it seems that from many researchers' point of view, DfRem is not simply a "DfX" but, in fact, several different factors to be considered simultaneously (Hatcher et al. 2011). For example, Sundin (2009) identified the relationship between different product properties and specific remanufacturing steps, as illustrated in the "RemPro Matrix" (See Figure 1).

In the case of the automotive industry, a sector with great potential for the application of remanufacturing practices, it is not uncommon for an Original Equipment Manufacturer (OEM) to deliberately block remanufacturing through designs or their own collection schemes in order to stifle this kind of activity, which is viewed as competition by its own new products (Hammond et al., 1998; Parkinson and Thompson, 2003; Matsumoto et al., 2011).

Remanufacturing Step / Product Property	**Inspection**	**Cleaning**	**Disassembly**	**Storage**	**Reprocess**	**Reassembly**	**Testing**
1. Ease of Identification	x		x	x			x
2. Ease of Verification	x						
3. Ease of Access	x	x	x		x	x	x
4. Ease of Handling			x	x	x	x	
5. Ease of Separation			x		x		
6. Ease of Seguring						x	
7. Ease of Alignment						x	
8. Ease of Stacking				x			
9. Wear Resistance		x	x		x	x	

Figure 1. *RemPro Matrix (Sundin et al., 2009).*

However, if the OEM is directly involved in the remanufacturing of its products, the following benefits can be obtained if they choose to participate in DfRem: Higher efficiency of existing remanufacturing activity,

e.g. reduced material waste or reduced disassembly times resulting in higher profitability of operation; preparing for future legislative changes that make end-of-life responsibility a necessity.

Hatcher et al. (2011) propose the use of concepts of existing design approaches and research methodologies considered relevant for the improvement of the DfRem. The advantage of using methods known in the industry, such as the implementation and modularization of the QFD (Quality Function Deployment) tool, is an indication that the designer may already be using these tools / methods or understand and experience them, which simplifies the integration of DfRem.

In addition, these methods have other benefits widely appreciated beyond remanufacturing interests, for example, platform design is most commonly employed to reduce manufacturing costs and simplify the product development process. However, as these approaches are not designed for DfRem purposes, they may not provide assistance concepts and, in fact, do not provide the designer with guidance on how DfRem can be executed.

In the research conducted by Hatcher et al. (2011) he provides a summary of the key findings and recommended

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research theories for DfRem. While it is commonly accepted that any design approach to remanufacturing should consider both product and process, some scholars believe this is not enough, and that DfRem should not be done in isolation, but should simultaneously consider other issues such as fabrication, assembly and environment.

3.5 Eco-design methods

In this work, given the importance of the theme in relation to the product development process and the life cycle attributed to it, as well as the principles of Circular Economy, it presents some eco-design methods focused on the integration of different "end-of-life" strategies, especially attention to remanufacturing to reduce product life cycle impacts on the environment. In this way, Eco-design methods are considered as systematic means to deal with environmental issues during the product development process (Baumann et al., 2002, Byggeth, 2006).

According to Pigosso et al 2010, among eco-design methods aimed at end-of-life alternatives, such as remanufacturing, presented five methods to demonstrate the application of eco-design to obtain more sustainable products through a project that allows a sequence to be defined. disassembly and / or evaluate the design according to its critical 'end of life' aspects. The five eco-design methods for "end-of-life" products are presented below.

Product designers can make modifications to the product design and evaluate the effect caused by each change. When defining how and with what material the product will be manufactured, parts and processes are chosen considering environmental and economic information. Then, it will be able to access and modify the available database and simulate end-of-life results. Figure 2 illustrates the inputs and outputs in the method and shows relationships between product design team and program.

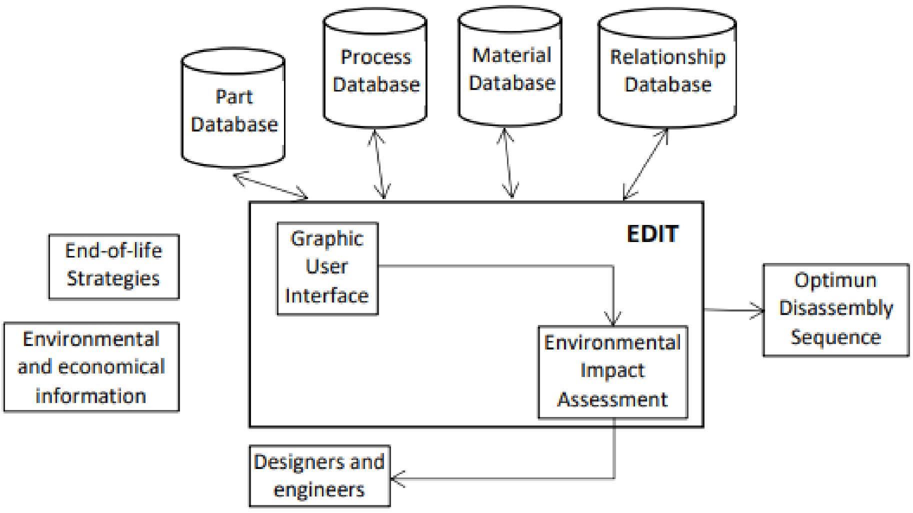

FIGURE 2. *Main inputs and outputs for EDIT. (Spicer and Wang, 1997)*

D4N Software

D4N is software described by Murtagh et al. (1999) that provides guidelines for product redesign and product lifecycle analysis. With this tool, the designer analyzes the product according to previously established ecological and economic metrics. The goal is to make the redesign process simpler for designers and make the process easily evaluated. The system can leverage existing data from 3D-CAD models of product design. Data from CAD systems is automatically extracted and located in a connection chart, allowing the generation of a disassembly sequence so that important components can be removed quickly, avoiding unnecessary disassembly. With CAD files you can determine the relationships of product parts. The input-based program (disassembly rules imposed by the designer) generates a disassembly sequence, indicating the order in which parts can be removed, ensuring that important parts (ecologically and economically) are removed as early as possible, thus avoiding unnecessary disassembly. Figure 3 illustrates the general idea of the D4N concept. The results are graphs and guidelines for redesigning during the early stages of the project, so design changes are low cost and highly effective.

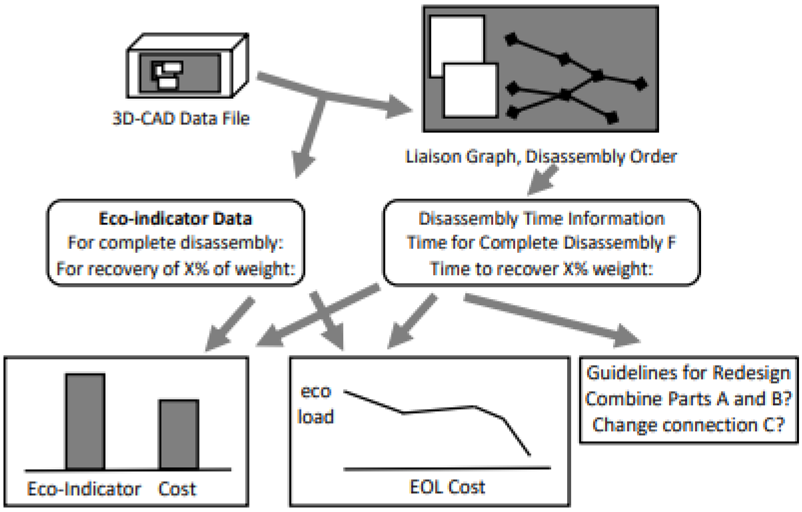

FIGURE 3. *Model of the D4N concept (Murtagh et al., 1999).*

Environmental Design Support Tool (EDST)

EDST was developed at the University of Technology of Texas by Yu et al. (1999) designed to support the early stages of product design, based on a disassembly model and decision making and database management system. To assess the environmental performance of a product with this tool, according to the authors, disassembly is the first step and provides the necessary time, number of components and other information for this operation. Analyzes disassembly capacity, material suggestions, percentage of disassembly fasteners and recyclability and evaluates design in terms of its environmental sustainability. It generates an index number to help evaluate the disassembly process, where the higher the number, the more difficult disassembly will be. Figure 4 demonstrates the relationships between the designed product disassembly model and the database information to generate the index number, allowing the designer to evaluate the consistency of his disassembly process.

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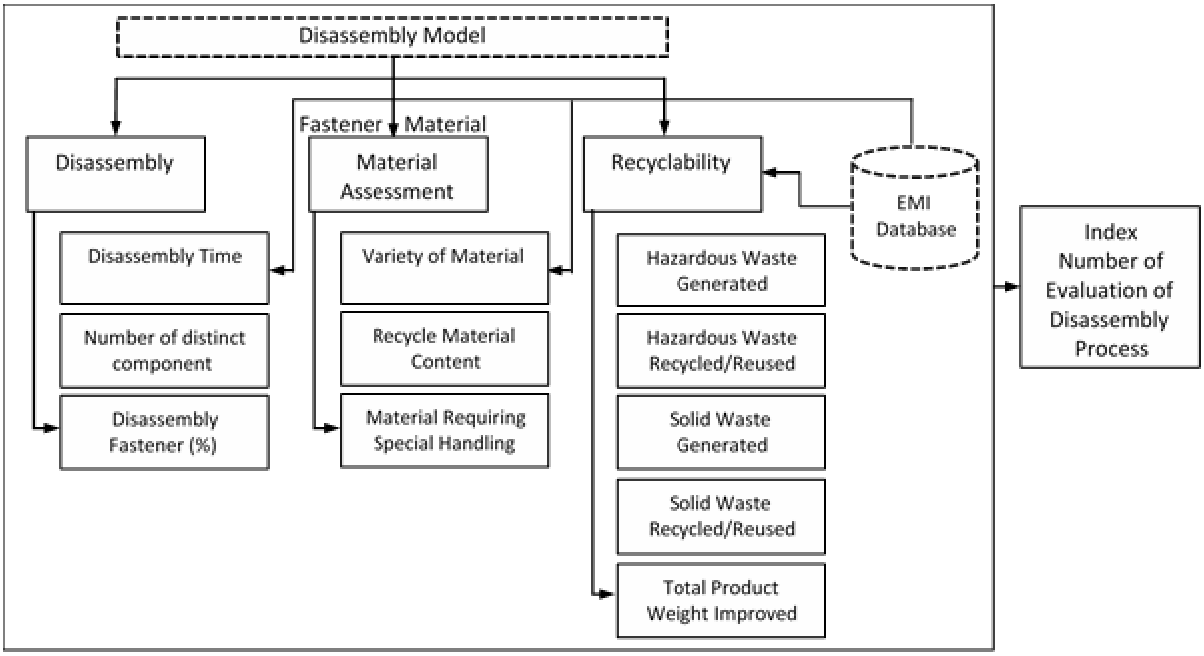

FIGURE 4. *EDST: Relationships between the disassembly model (Yu et al., 1999).*

Method for assessing product adaptability (MAAP)

Willems et al. (2003) describe that the main purpose of this method is to evaluate product compliance in the assembly, maintenance, repair, upgrade and remanufacturing processes. The conformity of a product is represented by a metric, µ adaptation, which is calculated by the program. The more this value tends to one (1), the better the design is adaptable, the more it tends to zero (0), the worse it is.

The method has specific sub-metrics that are then divided into sub-criterias: parts (components and removal direction), connectors (number of different components in each group, number of different components, number of connectors and tools), space (visibility, range, identification and direction for disassembly), remanufacturing (disassembly maintenance, assembly and architecture structure), repair (disassembly, assembly and architecture structure repair) and upgrade (functional and decoupling interface). Figure 5 contains all sub metrics and related criteria used in the MAAP method to obtain the µ adaptation value.

Product Life Cycle Planning (LCP)

LPC was described by Kobayashi (2005) as a methodology to help the designer establish a concept of eco-designing a product and its life cycle. Product Lifecycle Planning (LCP) is a systematic methodology that allows the user to include details regarding environmental requirements regarding the life cycle, aspects of the environment that are integrated with quality, and costs in the early development phases, while respecting customer demands such as cost and performance. The method focuses on product maintenance, service life extension, product or component reuse and recycling. Figure 6 represents the information flow in the LCP Methodology and the input data required for each step. You can understand the feedback process at each step to optimize product design.

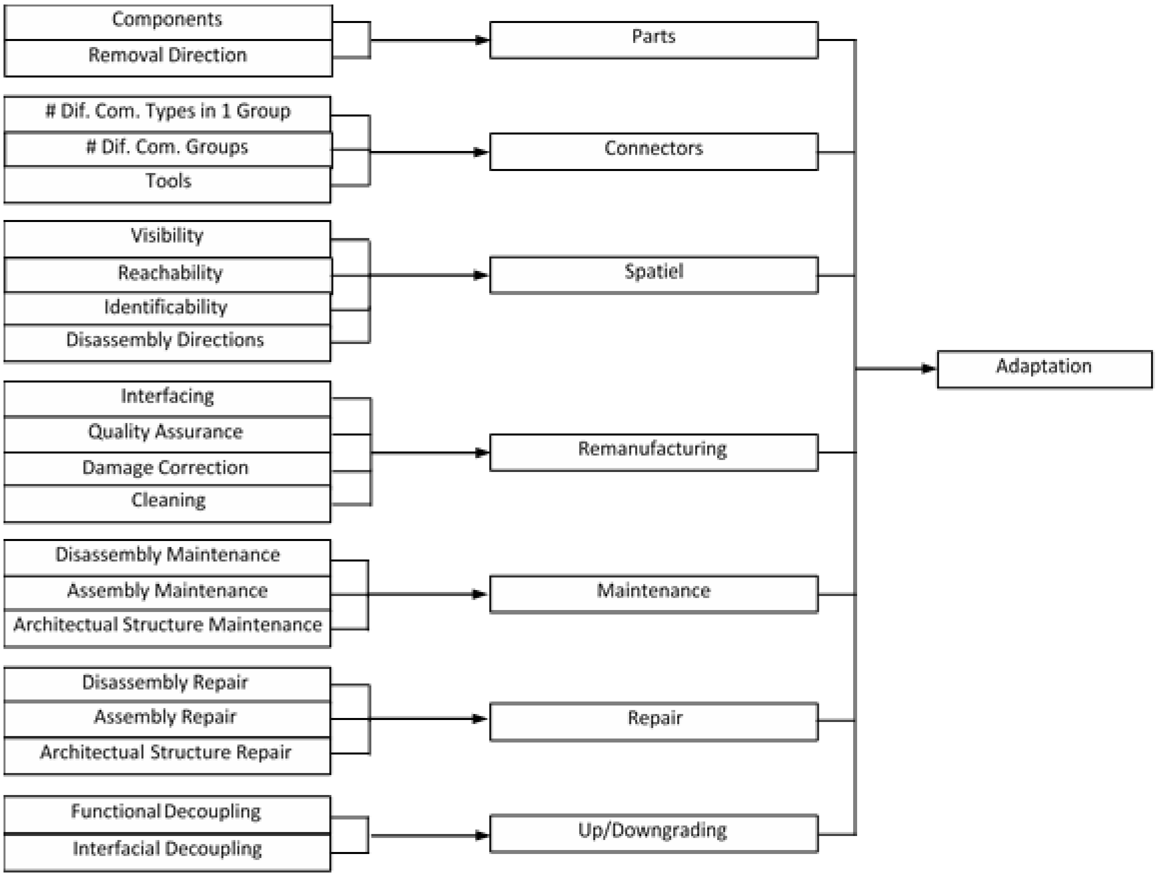

FIGURE 5. *Submetrics and criteria considered in obtaining the compliance metric (Willems et al., 20003).*

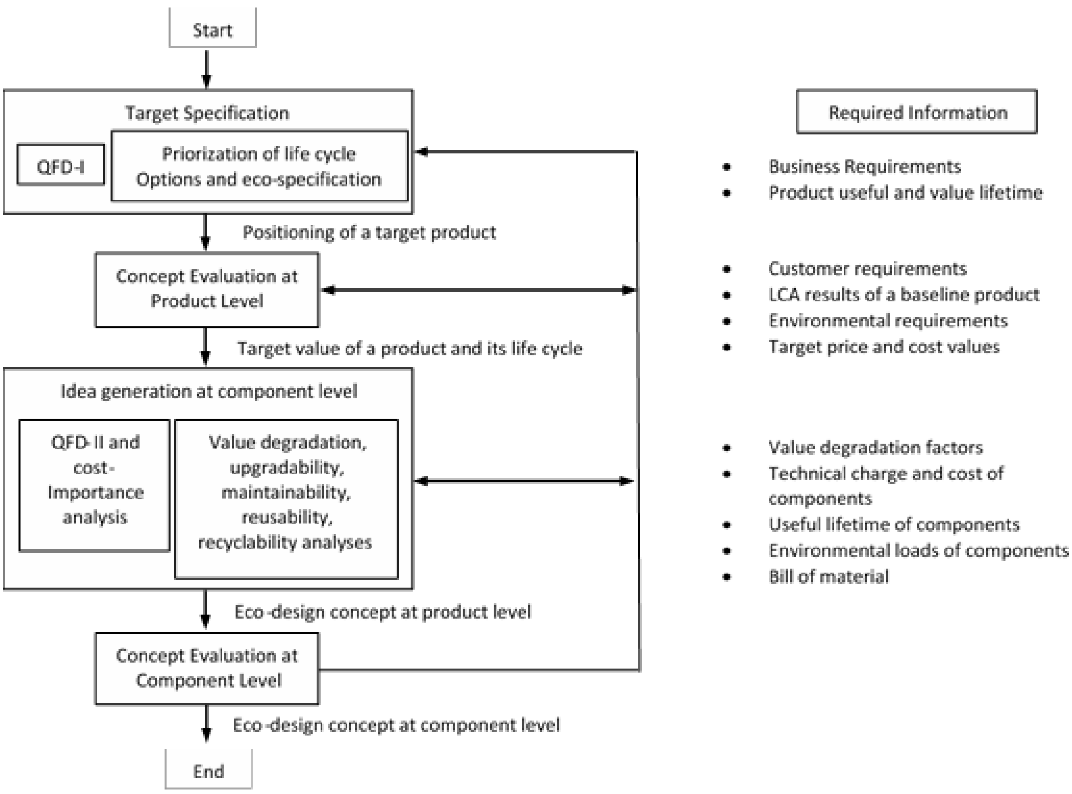

FIGURE 6. *LCP Methodology (Kobayashi, 2005).*

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4. Final considerations

Products designed today will be tomorrow's waste, and a company that plans ahead of time can gain competitive advantage. In this scenario, product service systems are an emerging marketing concept in which manufacturers will retain ownership of the physical product and instead sell the service that the product offers. This system fully adheres to the Circular Economy.

The remanufacturing process as part of the Circular Economy restorative process proves to be an "end-of- life" alternative to products and can become increasingly important, thereby reducing manufacturing costs and reducing the extraction of non-renewable materials. In addition to providing technical or biological nutrients for other manufacturing processes. Thus, closing the restorative and regenerative cycle of the product, just as eco-design methods are made available to designers.

It can be understood that these methods allow the designer to alter and evaluate different end-of-life strategies, even because not all product components can be remanufactured.

The tools analyzed here tend to integrate customer needs, environmental requirements, and economic considerations such as the use of materials and manufacturing processes, remanufacturing, and technological upgrading of products. This makes the product design process more interesting for organizations and more economically viable.

The methods emphasize how important the disassembly process is to assist with end-of-life analysis of products. For example, the EDIT, D4N and EDST methods use disassembly planning as an economic strategy, others consider it one of the means to improve the environmental quality of products. The decision on which method to use should be made based on the products to be developed as well as the strategy of the organization.

Significant price increases, increased volatility, and increasing resource pressure have alerted business leaders and policy makers to the need to rethink the use of materials and energy. Therefore, many variables need to be considered to implement a remanufacturing system. Variables such as government laws regulating companies' environmental activities, a reverse logistics system for products to return to their original manufacturers and thus be remanufactured.

One aspect that caught our attention was the fact that when we searched the Scopus and Web of Science databases by combining the keywords that describe each of the five methods (EDIT, D4N, EDST, MAAP, LCP) and “design product”, we only found a real case study applying the EDIT methodology (Dobes et al., 2017), whose results showed that the tool is effective in helping companies to identify weaknesses and potentials for improvements. This leads us to conclude that although there have been eco-design tools for 20 years, there is still a need to carry out more case studies in a scientific way that allow to spread their application in real environments and improve their performance.

We conclude that it is an ideal time, as many argue, to reap the potential benefits of Circular Economy and the use of eco-design in product development and the implementation of a financially and socially viable remanufacturing process. Organizational initiatives, support and consumer pressure are important for the world to make progress and make significant changes towards circularity and social sustainability.

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Remanufacturing process: literature review and gaps for further researches

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Abstract

Environmental regulations, consumer interest in environmentally friendly products or green products, scarce resources and the possibility of profitability have motivated companies to consider remanufacturing as part of the business model. The objective of this work is to identify the approaches and gaps in the remanufacturing process, as well as to characterize the contribution that academic publications can give to research in developing remanufactured products. The research strategy used to reach the objective was systematic literature review. Among the most important approaches identified in the literature are the Design for Remanufacturing to extend the product life cycle, application of product Life Cycle Assessment techniques to reduce energy and material resource expenditures in manufacturing processes, planning of integrated systems between services and products for resource conservation and environmental strategies, affirmation of the Circular Economy for remanufacturing and recycling applications, development of regulatory policies for the global remanufacturing system. Main gaps point to a lack of performance indicators definition of remanufacturing-related processes, uses of Life Cycle Assessment techniques to measure the environmental impact associated with remanufacturing activities, and the development of regulatory policies. The authors of this article believe that the information presented here can be useful for researches in their future studies and for industry professionals interested in improving manufacturing processes.

Keywords: Remanufacturing Process, Sustainability, Business Model, Circular Economy.

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1. Introduction

Due to new consolidated environmental regulations, reflecting society's desire for sustainable development, the recovery of end-of-life (EOL) and end-of-use (EOU) value of products are strategies that have gained attention from academic researchers, companies and decision makers around the world (JOHN ET AL., 2017; YU & SOLVANG, 2018). The EOU strategies are thought of in situations where the user has the opportunity to return a product at a certain stage of life (CAMPOS ET AL., 2017). While the term EOL indicates that a product has completed its service and reached the end of its useful life, with strategies then being configured to extend product life, (KONGAR, E. et al., 2015).

Different strategies of product recovery or EOL are possible, with alternatives such as reuse, remanufacturing and recycling presenting common objectives that propose the extension of the useful life of products and a decrease in the resources used (DENG, QIANWANG; LIU, XIAHUI; LIAO, HAOLAN, 2015). Reuse is defined as the second-hand trading of products for use as originally designed. Remanufacturing can be described as rebuilding the product by preserving the added value and energy converted into the product during the original manufacturing process (eg, labor, material or energy), while recycling attempts to recover only the value of the product material. (GUIDAT ET AL., 2014).

Environmental regulations, consumer interest in environmentally non-polluting products, resource scarcity and profitability motivate manufacturing companies to consider remanufacturing as part of the business model (ESMAEILIAN ET AL., 2016; ILGIN, MA, GUPTA , SM, 2016b; JINDAL, A., SANGWAN, KS, 2016).

Remanufacturing can contribute to solutions regarding natural resources use and reduce the environmental impact, making it very timely to preserve the development of society and promote the circular economy. Society is increasingly demanding about the origin of the products that are consumed, so production models that have discard as their end result have become outdated in the face of the complex socio-environmental reality. (JENSEN, ET AL. 2019).

In order to keep up with new consumer desires, companies need models that help design products with a broad view of the development process, from strategic planning to product recall. Therefore, remanufacturing processes should be thought through from the initial stages of the product design (YANG, S. S., ET AL.2017b). Therefore, engineering challenges are in the design of products and processes with greater utility and less environmental damage (YANG, S. S., ET AL.2016a).

Thus, the objective of this work is to identify how the concept of remanufacturing is being considered within the product development process through the analysis of academic publications that link the development of remanufactured products to sustainable development. In order to do so, we used the articles on remanufacturing indexed mainly in the Web of Science database in the last 5 years.

2. Remanufacturing

For residual products two possible long-term destinations are considered: reuse (closed circuit) or dissipative losses (open circuit) (Ayres, R; Simonis, U., 1993). For the closed circuit aspect, King et al (2006), present some strategies related to the extension of the term of life of a product and / or resource: repair, recondition, remanufacture and recycle.

From the four strategies described above, recycling and remanufacturing increase the utilization of materials and components used, conditioning them to reduce the consumption of raw materials and increase the value of the residue (ZLAMPARET ET AL, 2017).

A fifth strategy, not pointed out by King et al (2006), is cannibalization, which refers to the removal of a well-conserved component of a product for the repair of similar products / equipment. The cannibalization of parts for reuse is common in the aeronautical industry, according to Wakiru, et al (2018).

Extending the life of the product through recovery options can help reduce the consumption of natural resources and environmental pollution, such as remanufacturing, which is considered the most suitable product recovery option for automotive parts, as presented by Chakraborty, K .; Mondal, S .; Mukherjee, K. (2017).

For Lund and Hauser (2010), remanufacturing can be defined as the process of restoring products that are not fully functional, discarded / collected, to market them as a new one. On the other hand, remanufacturing, as a practice of eco-efficiency technology, is the process by which used products are recovered, processed and sold as new products in the same market or in a different one (WANG ET AL, 2018).

Overall, remanufacturing proposes the return of a previously used product with an effectively equivalent level of form and function to when it was new. In some cases, remanufacturing may upgrade a product to a condition beyond its original state, correcting, for example, design flaws of the original product or adding functional or aesthetic enhancements that were not present in the original product, Original Equipment Manufacturer - OEM, (KRYSTOFIK ET AL, 2018).

Corroborating, according to XU (2018), remanufacturing is an important part of modern and green manufacturing, promoting resource conservation and making the cycle of utilization more comprehensive.

The remanufacturing process is an industrial process in which a considerable volume of similar products are collected, dismantled and recovered in order to have a new and useful life. The collected product, called core, is inspected and disassembled and then goes through the following phases: tests, repairs, cleaning, parts inspection, updating, parts replacement and reassembly. At each phase, quality control is ensured by specific measures, making sure that the product meets or exceeds new product standards (SUNDIN, 2004).

Remanufacturing is generally applicable to complex electromechanical and mechanical products, especially aircraft and automobiles, which have cores that, when recovered, will have a high value, relative to their market value and their original cost. Another considerable aspect of remanufacturing is the environmental one, which preserves the energy that is used to modulate the components in their first life. It is estimated that a remanufactured product requires only 20 to 25% of the energy used in its initial manufacture, according to Lund (1985) apud King et al. (2006).

A well structured and managed product development process is necessary to reduce development time, manage risks, develop better products that meet quality requirements, and achieve satisfactory financial results (CASTELLION & MARKHAM, 2013 apud ONOYAMA ET AL, 2018).

A relationship between remanufacturing and the product development process generally occurs in the post-development phase, at the product discontinuation stage. However, when considered as an integral part of planning, remanufacturing is present in the conceptual design stage. The conceptual design of a product that will be remanufactured is emphasized with the techniques of Design for "X" (DFX), where "X" is an interesting

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characteristic of the product to be optimized to enable its remanufacturing, according to Sonego et al. (2015).

DFX tools also include Design for core collection, Design for multiple lifecycle, Design for upgrade, Design for Evaluation, where all these tools enable remanufacturing in order to preserve the parts of the product without damage during disassembly, to preserve and then use them in Design for Remanufacturing (MATSUMOTO, MITSUTAKA ET AL., 2016; AZIZ, N. A. ET AL , 2016; AKTURK, M. S., ABBEY, J. D., GEISMAR, H. N. 2017).

3. Method

The technical procedure used in this work was bibliographical research through the analysis of the academic production in the Web of Science database, during the last 5 years.

The work was carried out in three stages. The first stage sought a bibliometric survey of the scientific works constructed from the perspective of remanufacturing, defining a set of articles to be analyzed; the second stage used the selected articles and identified the main authors and works, the respective countries in which the published research originated and the channels of publication of the articles; in the third stage an analysis of the link between the product development process and the remanufacturing process was made, as well as the identification of gaps and future perspectives.

Actions of the method:

- The bibliographic search was carried out with flexible terms related to remanufacturing, so the truncation symbol (*) was used in the search of publications of the last 5 years in the Web of Science database as follows: remanufactur * or re-manufactur *;
- The selection of publications was done by keywords inserted in the Web of Science's website. These keywords were pointed out more frequently by HistCite® and VOSviewer® softwares. Keywords used in the selection were: china, business, policy, management, optimization, model, original equipment manufacturer (OEM), supply, decision, sustainability, industry and development.

The result of combining keywords with the flexible terms of the word remanufacturing was the selection of 169 publications out of 1451, in September 2018.

4. Results

Searches using the boolean operator "or" with the words "remanufactur*" and "re-manufactur*" in the Web of Science database have shown that studies related to remanufacturing go back to the 1960s, with concern for the quality of remanufactured products, as presented by Bauer (1961). However, it is known that remanufacturing started earlier, driven by the Second World War when remanufactured products were used on a large scale, supplying the need of society, largely because of the shortage of resources in that period and the lower cost of remanufacturing.

In this sense, remanufacturing is one of the approaches that lead to the recovery of products and not to discarding or recycling, a concept used and diffused by companies with high technology such as Fuji Film, Xerox, Kodak, IBM Europe, Caterpillar, Ford engines, BMW and Volkswagen that had already been developing remanufacturing activities / processes for some decades (KERR & RYAN, 2001). Recently, according to Zlamparet et. (2017), the continuity in the application of remanufactured product manufacturing processes by large corporations such as IBM, SIEMENS, and XEROX, which offer updates in its remanufactured products, means products with a new interface, updated software and hardware with efficient performance and a warranty.

4.1 Analysis of the evolution of publications, country of origin and institutions

Figure 1 shows the evolution of academic production regarding remanufacturing in the 10 year period (2008-2018), the last 5 years representing more than 50% of the publications. Since 2014 an average of more than 200 scientific works have been published each year. In 2017 we have the largest number of works, with 396 publications about remanufacturing, showing a rise of the subject. The sample represented by the lower bars on the right of figure 2 show the evolution over the years, so we can observe equality of behaviour given the comparison between the sample and the original data presented in the series / line graph.

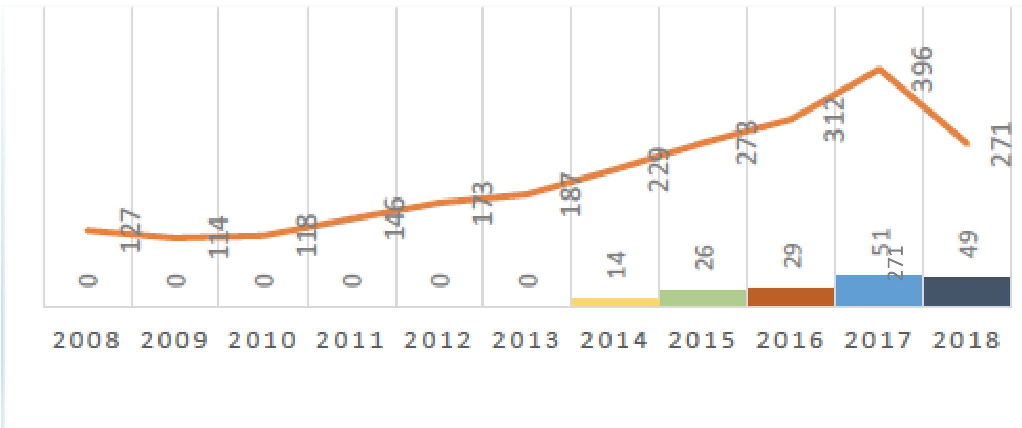

Fig1: Publications between 2008 and 2018. Source: Adaptation Web of Science (2018)

Figure 2 shows the characterization of publications according to the country of origin. The sample presented 37 countries, highlighting China, United States and Canada, which constitute almost 50% of the analyzed publications.

The US and the EU have regulations for remanufactured electronics, this regulation being important because 60% of non-hazardous waste produced by manufacturers requires legislation to reduce the environmental impacts of these products, hence remanufacturing strategies play a crucial role for both original equipment manufacturers (OEMs) and independent remanufacturers to be competitive within the supply chain (SEPÚLVEDA ET AL., 2010; AL., 2017).

In the USA there are more than 6,000 companies involved in remanufacturing, covering approximately 113 remanufactured products (LUND & HAUSER, 2010; CHAOWANAPONG ET AL, 2018). In the United

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Kingdom remanufacturing activities are estimated at £ 2.4 billion a year, and the effect is equivalent to a reduction in emissions of more than 10 million tonnes of CO2 / year (MATSUMOTO, MITSUTAKA ET AL., 2016). It can be seen, then, that high competitiveness drives the US and the UE to the development of remanufacturing and sustainability practices.

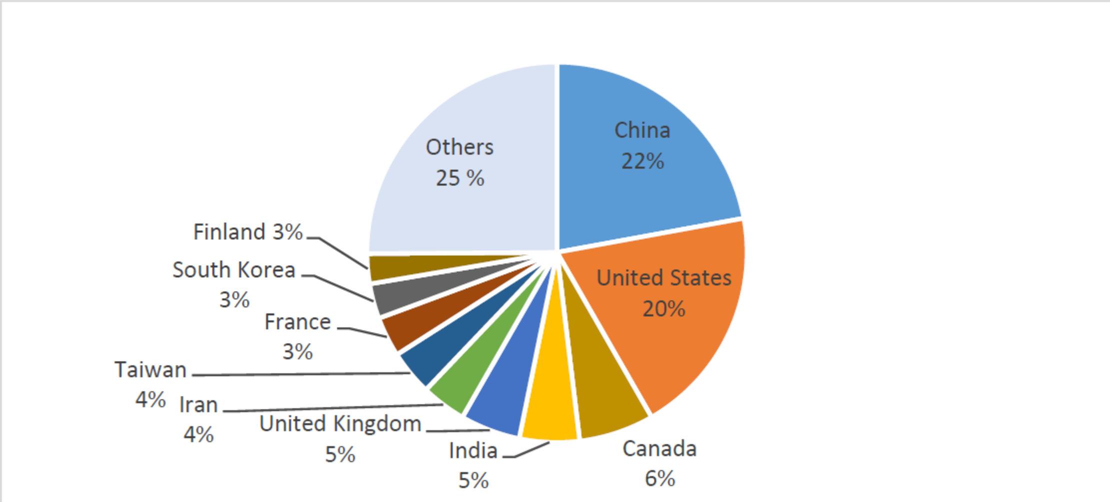

Fig2: Country of origin for publications: Source: Adaptation of Web of Science (2018)

China has the largest number of publications and the government there encourages the practice of industrial remanufacturing, which gradually formed in the late 1990s, based on equipment maintenance and engineering development. The development of remanufacturing in China has already achieved significant results in several industrial applications with the increase of state-of-the-art technologies for equipment remanufacturing, as well as promoting concepts of circular economy and resource conservation in Chinese manufacturing (XU, 2018).

The Chinese government, in view of the relevance of the worldwide remanufacturing industry, the pressure to reduce pollution, and the preservation of energy sources, has produced a series of regulatory policies and guidelines for the remanufacturing industry, in particular the Technical Policy for Automotive Product Recovery (TPAPR), which since 2006 has aimed to promote the development of the auto parts remanufacturing industry in China (QU ET, AL, 2018). In 2015, the Chinese government launched the Industrial Master Plan: "Made in China 2025" which proposes to vigorously develop industrial and service remanufacturing. The plan covers the industrial development of state-of-the-art technology enterprises (XU, 2018).

4.2 Analysis of scientific journals

Table 1 shows periodicals that stood out in the analyzed sample. The Journal of Cleaner Production presents the largest number of publications, with a percentage of 18.93%, this journal stands out in the production of articles aimed at cleaner production, sustainability and the environment.

Table 1– Description of Publications: Journals

Source Titles	Number of Publications	%
Journal of Cleaner Production	32	18,93%
International Journal of Production	12	7,10%
Sustainability	10	5,92%
International Journal of Production	8	4,73%
European Journal of Operational Research	6	3,55%
Computers & Industrial Engineering	4	2,37%
International Journal of Advanced	4	2,37%
Journal of Industrial Ecology	3	1,78%
CIRP Journal of Manufacturing Systems	3	1,78%
Journal of Intelligent Manufacturing	2	1,18%
Others	85	50,30%

Source: Adaptation of Web of Science

It is worth mentioning that remanufacturing is present as a source of knowledge among important journals that disseminate engineering and manufacturing knowledge, such as: International Journal of Production Economics, International Journal of Production Research, European Journal of Operational Research, among others.

When analyzing the impact factor of journals we use the Journal Citation Reports (JCR), which is a recognized basis for evaluating periodicals indexed in the WOS. The impact factor identifies the average constancy which an article in a journal is quoted in one year (UFSCAR, 2018). It is estimated by dividing the number of citations in the year by the total number of articles published in the previous two years.

The Journal of Cleaner Production has the highest impact factor, among the journals observed in Table 1, the impact factor is 5,651, which means that on average the articles published in this journal in the previous two years were quoted approximately five and a half times (Clarivate Analytics, 2018).

In the Journal Citation Reports (JCR), it can be observed that the Journal of Industrial Ecology, Sustainability, Journal of Cleaner Production are categorized in Green & Sustainable Science & Technology and Environmental Sciences which corroborates with what has already been presented about the indispensable role in environmental conservation of the processes of remanufacturing and sustainable development. The origin of the articles that compose these journals were predominantly Chinese in the case of the periodicals Sustainability and Journal of Cleaner Production, and predominantly North American for Journal of Industrial Ecology.

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4.3 Analysis of authorship in publications

A bibliographic milestone for remanufacturing occurred in 1984 when Professor Robert T. Lund presented prominent studies on remanufacturing, identifying barriers and advantages of remanufacturing operations with an emphasis on industrial business (Liu et al, 2016).

Also noteworthy is the theoretical study by Ilgin & Gupta (2010a) in which remanufacturing appears as an alternative to Environmentally Conscious Manufacturing and Product Recovery (ECMPRO). This work presents the most relevant methodologies in the management of manufacturing operations, with remanufacturing being considered one of these methodologies.

As observed, in table 2, Gupta is included among the authors that stand out regarding remanufacturing studies, in the last decade. Ten authors are presented in table 2 and they represent 10.71% of the publications. Bin-Shi Xu, Surendra M. Gupta, V.Daniel R Guide Jr., and Erik Sundin are well-established authors in this area. Hong-Chao Zhang, Andrew Y.C. Nee, Sara Behdad, and Yixuan Wang are authors of great relevance and prominence in the last 5 years. For example, Andrew Y.C. Nee presents all his studies within the period of this research, but Hong- Chao Zhang is the author who presents the highest number of publications in this range. This confirms the predominance of Asian countries, especially China.

Table 2 – Description of authorship in publications

Authors	Publications	Nationality
Bin-Shi Xu	65	China
Surendra M. Gupta	54	India
V.Daniel R Guide Jr.	43	United States
Hong-Chao Zhang	39	China
Yongjian Li	23	China
Erik Sundin	22	Sweden
Sara Behdad	19	United States
Rajesh Srivastava	19	India
Yixuan Wang	19	China
Andrew Y.C. Nee	18	Singapore

Source: Adaptation of Web of Science

In the sample, 489 authors were identified, with 88% of them having only one publication. According to Guarido Filho et. al (2009), these researchers are categorized as one-timers, in other words, sporadic authors /

researchers with only one publication during the analysis period. It is worth noting that this classification becomes dynamic in the medium term as the authors may change categories in future periods.

4.4 Trend Analysis and Gaps

This article aims to present the trends of future studies for remanufacturing, so the most quoted publications in the Web of Science index in the last 5 years were identified, these publications being shown in table 3. The works of Lieder & Rashid (2016) and Bakker et al. (2014) stand out, with more than 100 citations. While the work of Lieder & Rashid (2016) gives an updated theoretical overview of circular economics, Bakker et al. (2014) present a sustainable product project for life cycle extension, with remanufacturing as a strategy. Common aspects of these works are the use of the remanufacturing concept for the development of sustainable processes.

Table 3 - Most relevant publications in the past 5 years

Authorship	Year	Title	Source Titles	Subject	Research Focus
Behzad Esmaeilian, Sara Behdad & Ben Wang	2016	The Evolution and future of manufacturing: A review	Journal of Manufacturing Systems	Trends for the future of manufacturing	Theoretical
Conny Bakker, Feng Wang, Jaco Huisman & Marcel den Hollander	2014	Products that go round: exploring product life extension through design	Journal of Cleaner Production	Application of product design for life cycle extension.	Aplication
Mattias Lindahl, Erik Sundin, & Tomohiko Sakao	2014	Environmental and economic benefits of Integrated Product Service Offerings quantified with real business cases	Journal of Cleaner Production	The study quantifies environmental and economic benefits from integrated product and service delivery from an optimized life cycle perspective	Aplication
Serra Caner Bulmus, Stuart X. Zhu & Ruud Teunter	2014	Competition for cores in remanufacturing	European Journal of Operational Research	Study of competition the color picker (cores) between original equipment manufacturer (OEM) and an independent	Aplication

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Kannan Govindan & Maria Nicoleta Popiuca	2014	Reverse supply chain coordination by revenue sharing contract: A case for the personal computers industry	European Journal of Operational Research	A model for applying reverse logistics in a personal computer industry	Application Modeling
Adem Örsdemir, Eda Kemahlıoğlu-Ziya & Ali K. Parlaktürk	2014	Competitive Quality Choice and Remanufacturing	Production and Operations Management	Development of decision-making model for remanufacturing that evaluates the choice between OEM and IR (Independent Remanufacturer)	Modeling
J. Michael Wilson, Cecil Piya, Yung C.Shin, Fu Zhao & Karthik Ramani	2014	Remanufacturing of turbine blades by laser direct deposition with its energy and environmental impact analysis	Journal of Cleaner Production	Turbine Airfoil Repair Modeling and Life Cycle Assessment Application	Application Modeling
Xiqiang Xia, Kannan Govindan & Qinghua Zhu	2015	Analyzing internal barriers for automotive parts remanufacturers in China using grey-DEMATEL approach	Journal of Cleaner Production	Presents a model for barrier assessment for remanufacturing implementation	Application Modeling
Saurabh Agrawal, Rajesh, K.Singh & Qasim Murtaza	2015	A literature review and perspectives in reverse logistics	Journal of Cleaner Production	Literature Review Reverse Logistics	Theoretical
Marcus Linder & Amir Rashid,	2016	Towards circular economy implementation: a comprehensive review in context of manufacturing industry	Journal of Cleaner Production	Explores concepts related to circular economy	Theoretical
Nicky Gregson, Mike Crang, Sara Fuller & Helen Holmes	2015	Interrogating the circular economy: the moral economy of resource recovery in the EU	Journal Economy and Society	A circular economy critical study	Theoretical

Source: Adaptation of Web of Science (2018)

The theoretical work of Esmaeilian et al. (2016), was also renowned. In this paper, remanufacturing publications are categorized as: business models for product remanufacturing; production, scheduling and inventory planning; determination of recovery options; environmental and cost analysis of remanufacturing operations; the applicability of remanufacturing to product design.

To illustrate this, some of the most recent and relevant publications of the sample analyzed, regarding the number of citations, were categorized as proposed by Esmaeilian et al. (2016).

The pursuit of requirements for key product recovery technicians can be facilitated by efficient product planning, so for Gu et. al (2015) in the category "The applicability of remanufacturing to product design", a robust product design project is presented, where a model is developed to qualify the portfolio by divided it into non-remanufactured and remanufactured products.

Facing the need to adapt environmental and regulatory issues and reduce production costs, new business models are emerging, so for business models for the product remanufacturing category, Wang et al (2014), propose an appropriate business model for remanufactured products when the manufacturer does not get involved in the remanufacturing process in the context of developing countries such as China.

To determine the best end-of-product options some decision tools are developed. In this context, Subulan, K .; Taşan, A. S., Baykasoğlu, A. (2015), developed a holistic model for a closed-loop tyre supply chain using mixed integer linear programming, for decision making regarding alternative recovery options such as remanufacturing, recycling and energy recovery, which were considered simultaneously in the model. This work can be categorized under recovery options.

Linder, M., Williander, M. (2017), promoted a discussion about the challenges of circular economics as innovation and a reluctance to consider its implementation. This work falls under the category environmental and cost analysis of remanufacturing.

Concluding the analysis of publications that are linked to the classification of Esmaeilian et al. (2016), it is worth mentioning the superiority of publications related to production, scheduling and inventory planning., as being the most recurrent theme within the sample, optimally presenting the production and inventory planning of the remanufacturing industry, such as Niknejad, A., Petrovic, D. (2014) who developed an algorithm to solve inventory control and production planning problems for a generic integrated reverse logistics network.

Esmaeilian et al. (2016), concluded his work by addressing the fact that while recycling and remanufacturing were prominent at the beginning of the circular economy and may have surpassed the mere vision of end-of-life recovery, this would not be sufficient for sustainable success. According to this author, the true success of the circular economy will be due to new business models that extract real value from the product, such as: selling durable products; sale of service instead of products; supply chain efficiency; and product design strategies that can facilitate repair and extend product durability. In other words, Esmaeilian et al. (2016) mention Design for Remanufacturing and integrated between Product-Service Systems (PSS) as possible success factors for the Circular Economy

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Still in the categorization within the sample of analyzed works, there are themes that can be summarized by the following topics:

- Development of Design for Remanufacturing and Design for multiple lifecycle to extend product life cycle and promote the Circular Economy (MATSUMOTO, MITSUTAKA ET AL., 2016);
- Application of Product Lifecycle Assessment techniques to reduce energy and / or material resource expenditures in remanufacturing processes (KRYSTOFIK, MARK ET AL., 2018; KURILOVA-PALISAITIENE, J., LINDKVIST, L., & SUNDIN, E., 2018)
- Planning of integrated product-service systems (PSS) for resource conservation and environmental strategies, and affirmation of remanufacturing concepts for Circular Economy development (SOUSA-ZOMER ET AL., 2017);
- Provision and optimization of supply chains by aligning those involved in the supply chain: supplier selection, green chains, (ABBEY, J. D., GUIDE JR, V. D. R., 2018; GOLROUDBARY, S. R., ZAHRAEE, S. M., 2015);
- Remanufacturing element (OEM or IR) decision in emerging economy countries;
- Case studies in developing countries such as China and India (XIAO, L. ET AL., 2018);
- Barriers and economic opportunities in the remanufacturing industry (WANG, K., ZHAO, Y., CHENG, Y., & CHOI, T.M., 2014).
- Production schedules for products to be returned (BULMUŞ, S. C., ZHU, S. X., & TEUNTER, R. H., 2014; LAGE JUNIOR & GODINHO FILHO., 2016).

With the development of this study one can find some research gaps. Regarding the importance of robust product designs for remanufacturing, there is little research related to the integration tools used in design for remanufacturing (DFX's) at the product pre-development stage, different than the design tools used in the parameters optimization / conceptual design solutions, which have more consolidated research and are popularized in academia.

Other relevant gaps are: process performance indicators related to remanufacturing; uses of LCA techniques to measure the environmental impact associated with manufacturing and remanufacturing activities. Also, and within the sphere of regulatory policy development, there is a need to identify which model is most efficient: the Chinese, the American or the European, to foster the remanufacturing industry and motivational factors that encourage consumers to buy remanufactured products. All these methodologies and tools presented as gaps are indispensable for the success of operational sustainability and a sustainable world economy.

Recent publications point to the study of PSS integration and remanufacturing, making it a prominent theme for years to come, sharing society's interest and the trend for more sustainable products and services. Also recently introduced is the “de-and remanufacturing” concept, which is an innovative and technological approach to design, management control and remanufacturing development systems and has a key role in supporting the Circular Economy, according to TOLIO, T. et al (2017). This concept connects remanufacturing with the technological reality of products and processes in manufacturing / remanufacturing today.

5. Final Considerations

Product development planning is applied to meet the needs of consumers with a high level of quality, performance and efficiency. Remanufacturing is a broader concept related to product life extension and environmental preservation, so it becomes essential for the sustainable development of a product. The concept of the Circular Economy (CE) is contemporary and is present in society today. It drives remanufacturing practices to preserve resources, but, taking into account the observations made in this study, remanufacturing is not fully applied in the early stages of product design planning, with the academic contribution for remanufacturing in the early stages not being consolidated. Therefore, CE concepts need to be incorporated into the early stages of the remanufacturing product development process to give fully sustainable products.

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A systematic map for classifying studies on barriers related to circular economy, sharing economy, collaborative consumption, and product-service systems

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Abstract

The linear paradigm of take-make-dispose in production and consumption threatens global sustainability goals. Strategies for looping resources (e.g. as proposed in circular economy) have been discussed as a promising future, but not without a number of challenges or barriers in the transition phase. Consequently, barriers for realizing such strategies is a prominent topic in an increasing number of empirical studies. Following this trend, several of meta studies have compiled the barriers found in the literature, trying to summarize and generalize them; while others have cited or assumed the existence of a specific barrier and proposed a solution to overcome it. However, understanding of what type of barrier related to what type of circular strategy (e.g. reuse, remanufacture, recycle) is limited because scholars of emerging scientific areas use different concepts and language to frame their findings. Moreover, the fact that contextual factors may play an important role concerning the presence or absence of a specific barrier has been overlooked. Without a common framework to organize the findings, isolated knowledge does not cumulate. In this study, we developed a systematic map for classifying studies on barriers related to the emerging fields of circular economy, sharing economy, collaborative consumption and product-service systems. The purpose is to, first, classify and consolidate research knowledge in order to analyze the progress in these four research paradigms, and second, to provide a searchable database for future more rigorous systematic literature reviews. Five hundred and twenty-seven publications published between 2003 and January 2019 available in Scopus were reviewed and classified in a fine level of granularity, including whether barriers are the focus of the publication, how the barriers were identified by the publication (e.g. empirically, assumed, indirectly mentioned), whether the publication discuss or test a solution, the method used (e.g. case study, survey, interviews) and data source (primary, secondary). The systematic map helped to identify relevant contextual factors for one or a set of barriers in single empirical study, such as the circular strategy, geographical context, (i.e. country), level of analysis (e.g. business model, governance, product, user), and sector (e.g. accommodation, clothing, transport, electronics). Further, the map is an open source adaptive framework serving also as a digital database for researchers alike for extracting knowledge and contributing further to its development, through input and collaboration.

Keywords: Systematic Map, Circular Economy, Sharing Economy, Collaborative Consumption, Product-Service Systems

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1. Introduction

Research has intensified over the last few years in new strategies and mechanisms enabling a systemic change towards sustainability, defined consistently as large-scale changes in the present socio-technical and production- consumption systems (de Jesus and Mendonca 2018). Among few, research paradigms such as circular economy (CE), sharing economy (SE) or collaborative consumption (CC), and product-service systems (PSS), can be considered as part of the large-scale change efforts, which have gained traction across scholars and practitioners. Increasingly, their implementation into strategic goals and agendas of organisations, public institutions, and cities

frameworks has become more relevant. This can be attributed to the spreading awareness of natural resource exploitation, rocketing increases in waste, and other environmental externalities of current linear production-consumption processes (Korhonen et al. 2018; Robert et al. 2002). Furthermore, a possible business and innovation opportunity is suggested as natural resources continue to diminish (EMAF 2013). However, many barriers prevail in the transition to these alternative forms of production and consumption.

Hence, numerous publications have spurred the body of literature about barriers and challenges for looping material resources. It has also become evident that there is a complex interdisciplinary and multidisciplinary nature of studies underpinning these approaches. Although such cross-fertilisation on fields of science, research methodologies, and methods is widely embraced as fruitful, it can increasingly challenge the knowledge application in practice and transformation of it into actionable goals. Particularly, the circular economy and sharing economy paradigm are noted with criticism for being unorganised, offering little relevance for practitioners and policy makers (Korhonen et al. 2018). An overview of the most recent (systematic) literature reviews pertaining barriers towards circular economy (Camacho-Otero et al 2018; Ghisellini et al 2018, 2017; Govindan and Hasanagic, 2018; Kirchherr et al 2018; Liu et al 2018; Ranta et al 2018; Masi et al 2018); the sharing economy (Hira and Reilly 2017; Sposato et al 2017), and product-service systems (Gomez and Pasa 2003; Pessoa and Becker 2017; Shi et al 2017) area demonstrates the complexity in delineating the literature due to high variation in terms of: theoretical underpinnings, analytical frameworks, nature and methodology of studies, research methods used, and spread across publication journals. Meanwhile, no systematic literature review was found in relation to barriers in the context of CC. Additionally, more challenging are the case studies, ranging widely across industries and layers of the economy such as micro, meso, macro (Ghisellini et al 2018) as well as social layers applied onto them e.g. political, regulatory, community, organisational, or individual among others. Hence, a lack of clear systematic overview on knowledge production, organisation, and mapping regarding barriers and their context, arguably stagnates the scientific progress as well as application of knowledge; consequently, and most importantly, perturbs the implementation of solutions and policies that could effectively address the barriers. A consistent overview of the published scientific literature would be useful to academia and relevant stakeholders to plan future endeavors thereof.

Therefore, in an attempt to clarify the mass of studies and facilitate research progress in the aforementioned areas, we conducted a systematic map as part of an ongoing research project in Sweden. First, the purpose is to classify and consolidate research knowledge in order to analyze the progress in these four streams of research, and second, to provide a searchable database for future more rigorous systematic literature reviews that aim to answer specific research questions or extract in-depth analysis of the fields. Our framework initially focuses only on one side of the four dominant paradigms, by looking specifically from a perspective of barriers, obstacles, or challenges identified, conceptualised, and theorised regarding the implementation of CE, SE, CC and PSS, with a latter goal to identify solutions and mechanisms that address barriers in another forthcoming paper. The systematic map is a digital database for researchers alike, to be used for extracting knowledge and contributing further to its development through input and collaboration; hence, it will be an open source adaptive framework.

Arguably, although these four literature domains have developed onto their own path, there are commonalities in the approaches and they are considerably steered around core common principles. CE emphasizes redesigning products and processes to ensure continuous reuse of resources proposing an industrial system that is restorative or regenerative by intention and design almost mimicking natural ecosystem's processes (Korhonen et al. 2018; Kirchherr et al. 2017).

SE core principle inquires reusing products and increasing the utilisation rates of resources (products, goods, and services) through shared access to resources (Frenken and Schor 2017). SE was originally termed "collaborative consumption" (Botsman and Rogers 2010) and is often used interchangeably (Frenken and Schor 2017), however, both are included in the map as we will explain in the methodology. PSS includes

preventing or reducing waste through avoiding unnecessary purchases, increasing or extending the usable life of products, and creating value through leveraging unused assets or sharing existing items (Tukker 2015; Baines et al. 2007). PSS can be regarded as a subset instrument of realising CE and SE, without any explicit guarantee for reaching the outcomes which the CE initiative aims for (Kjaer et al 2019).

Essentially, the overarching principle of these paradigms, is to keep added value of material resources (i.e. consumer goods) circulating in the use phase through reuse, while reducing further natural resource exploitation and avoiding waste (Laurenti et al. 2016; Sinha et al. 2016). Another recurring concept across is the R-framework (e.g., Reuse, Repair, Remanufacture) with aims towards closing material loops. The R-principles suggests strategies or actions towards closing or narrowing material loops. While the number of R's included in the frameworks vary significantly (Kirchherr et al. 2017), they commonly highlight the need: 1) to use and manufacture products in a smarter way, e.g. reducing resource usage or rethinking the functionality of products;

to extend the total lifespan of products and individual components, e.g. through repairs, remanufacturing or reusing; 3) to use materials in a restorative and responsible way, e.g. through energy recovery and material recycling; and 4) to shift from ownership-based to access-based consumption, e.g. through circular business models (C2C and B2C offerings) (Arekrans et al. 2019). Another way to look at these is, for example, from the perspective of the concept of 'reuse'. With regards to consumers, four variations of reuse practice have been identified by Tukker (2015):

1. Consumers buying used goods from other consumers (transfer of ownership, C2C)
2. Consumers donating used goods to other consumers (transfer of ownership)
3. Companies offering B2C services instead of products (temporary access to goods/pay-per-use)
4. Consumers granting access to their private assets to other consumers (C2C) mediated by the internet (peer-to-peer sharing).

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The type 3 variation is a CE strategy referring to PSS; whereas type 4 can be understood as an emergent phenomenon of SE. Understandably, such reductionist simplifications may be intimidating and perhaps defying for the immense efforts of scholars put in the fields. As such, we chose to observe so only for the purpose of a pragmatic classification of the literature so as to begin a systematising research agenda among the scientific communities involved in these areas, which we hope will spark discussion and further contribution. Below we describe the methodology behind the development of the systematic map with the initial results we have obtained from such mapping.

2. Methods

Systematic mapping studies or scoping studies are designed to give an overview of a research area through classification and counting contributions in relation to the categories of that classification (Petersen et al. 2015). It involves searching the literature in order to know what topics have been covered in the literature, and where the literature has been published (Petersen et al. 2008). There is a range of reasons where a systematic mapping is considered suitable approach, as suggested by Okoli and Schabram (2011). In this study, the method was chosen to analyse the progress of a specific real world phenomenon (barriers) diluted in different streams of research (paradigms). The methodology for the systematic mapping process in this paper is largely adapted from the guidance developed in the fields of environmental sciences (James et al. 2016) and social sciences (Clapton et al. 2009). These works were consulted and consolidated into an overall process following the steps shown in Figure 1.

***Figure 1**. Mapping process.*

2.1 Aim and Objective

The aim of the study was to identify and systematically map published research on barriers that inhibit relevant stakeholders (e.g. business organizations, consumers, governments) to realise circular strategies. We focused further on the subsets of these which we conceptualised as circular loops: recycling, remanufacture, reuse, access- based non-ownership (e.g. sharing and servitization). This classification framework should allow for understanding in a fine level of granularity the relation of barriers and the context in which a study was carried out.

The research objectives (ROs) were to:

RO1. Classify the studies according to their different context;

RO2. Provide a searchable database for future more focused reviews; and,

RO3. Obtain a clearer overview of the literature on barriers regarding CE, SE, CC, and PSS

The following research questions (RQs) guided the construction of the map and the reporting of the results:

***RQ1**: What are the publication trends with regards to barriers in CE, SE, CC, and PSS?*

RQ2: *How are barriers framed across the paradigms and loop strategies?*

RQ3: *What research approaches, methods and sources of data have been used to identify barriers?*

RQ4: *How have barriers been identified in the literature to date?*

RQ5: *What is the contextual framing of barriers in relation to the level of analysis, industrial sector/product, and geographic spread?*

2.2 Protocol

To ensure that all researchers involved were aligned with the mapping process, we developed a detailed protocol document that included an initial study coding strategy (see Table 1). In addition, we found the work by Okoli and Schabram (2011), Denyer and Tranfield (2009), Xiao and Watson (2017) and Fink (2005) particularly helpful in developing the protocol for the coding and review. The protocol established the search engine, search string, criteria for inclusion and exclusion of studies, and guidelines and principles for the review team to do the mapping. It was iterated a number of times within the team to ensure consistency in the execution of the mapping by allowing that each team member understood the overall procedure and agreed upon scope, definitions and delimitations. This protocol was consulted and discussed weekly between researchers to follow up as the search progressed.

2.2.1 Search engine

A number of search engines were discussed and briefly scanned by all the researchers such as Scopus, Web of Science, Google Scholar, and EBSCO. The search engine chosen for the mapping was limited to Scopus since it contained more indexed articles than the rest in the areas concerning this review. According to Randhawa et al. (2016) and Fahimnia et al (2015), Scopus is the largest database in the fields of science, technology, medicine, social sciences, arts and humanities. Further, it indexes about 70 percent more sources than the Web of Science (Brzezinski, 2015) including comprehensive coverage of latest literature (Harzing and Alakangas, 2016).

2.2.2 Search string

While developing the protocol, a number of different search strings were tested. First, an understanding of the keyword ‘barrier’ was established where synonymous keywords were also discussed in relation to this e.g. hinder, obstacle, inhibitor, hurdle, challenge. These were all included in the search strings. Second, the researchers jointly discussed different streams of literature and simultaneously scanned the results of different search strings in the database regarding the domain fields: circular economy, sharing economy, product-service system, collaborative consumption. The publication overlaps of search strings including different combinations of keywords were explored. Specifically, keywords such as collaborative consumption, sharing economy, sustainable, sustainability, product service systems (or PSS), circular economy, and servitization combined with an additional filter of words related to ‘barrier’ were the focus of the initial scanning.

This experimentation led to some insights on how the different keywords were interrelated, as well as words to avoid. For example, ‘sustainable product-service- systems’ was initially considered, but was regarded as a significantly small subset of a much larger stream of literature which might be relevant. Furthermore, the abbreviation ‘PSS’ is not limited to Product-Service-Systems, but a number of other uses which creates false

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positives. The final search string resulted in:

(TITLE-ABS-KEY ("circular economy" OR ("product-service system") OR "sharing economy" OR "collaborative consumption") AND TITLE-ABS-KEY (barrier OR hinder OR obstacle OR inhibitor OR limitation OR hurdle)) AND (LIMIT-TO (LANGUAGE , "English"))

2.2.3 Practical screening

Fink (2014, pp. 55-56) lists several criteria upon which studies can be reasonably excluded from consideration for practical purposes of limiting the scope of the study. Publications were assigned as 'excluded' from the full abstract mapping when:

1. their main topic was not about circular economy, product-service system, sharing economy, or collaborative consumption (false positive);
2. they were not about barriers (false positive);
3. they were systematic review articles; or
4. no abstract was available.

A detailed protocol with the exclusion and inclusion criteria is shown in Appendix 1 at the end of the paper.

2.3 Search and calibration

The search was executed in Scopus and exported on January 23th, 2019, which resulted in 527 publications. The search was limited to abstract, title and keywords. Bibliographic information, including abstracts, of the resulting publications were imported into a shared online spreadsheet. Each publication was designated an identification number. All four members of the mapping team could access and edit the same sheet simultaneously.

In order to calibrate and align the understanding of abstract review process between the members of the review team, ten papers were distributed to each member for individual reading and coding of abstracts. The researchers then compared and discussed their coding and suggestion for inclusion or exclusion. This way, a notable difference in interpretations of important concepts was mitigated. As the researcher's suggestion for inclusion or exclusion varied within the team, it was agreed that all papers should undergo the same coding of abstracts (a systematic literature mapping) and that a filtering of the mapping result would be selected for a systematic literature review (SLR) to be continued in another forthcoming paper. The rationale behind this decision was that it would (1) allow for a more informed decision based on the accumulated learning from the mapping process, and (2) result in a more objective selection, as the decision for inclusion/exclusion per paper would be based on the coded criteria and not subjectively.

To ensure consistency in the coding, the team shared a working log, writing the progress, modifications in the working sheet, codes added, important points to be discussed or check by another member. A free-text field was used for leaving notes to explain the thought process. If consensus was not reached, it was brought up for discussion to the rest of the team. Furthermore, as the mapping was under progress, it was noted that the quality of the abstracts varied significantly. To make note of this inconsistency a five-point 'Coding confidence scale' was introduced, where the researchers' could rate how easily and objectively the requested information could be extracted (1-very low confidence; 5-very high confidence). This measure was added to enhance the rigor of the review. The team had also follow up meetings every second week during the coding phase to monitor progress.

2.3 Screening and coding

We developed a template, shown in Table 1 to code study metadata, outcomes, and contextual information based on the study objective. Each coding category was represented by a column in the shared working sheet. Some of the categories were predefined and some were grounded with an organic approach as they could not be specified a priori e.g. country.

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Table 1. *Coding system strategy*

WORK LOG

Reviewed by	Status	Coding confidence
Researcher 1	Done	1
Researcher 2	Undone	2
Researcher 3	In progress	3
Researcher 4	Check	4
	Exclude, out of focus (false positive)	5
	Exclude, no abstract available	

PARADIGM, LOOP STRATEGY, POSITION

Framed as	Circular loop	Position in supply chain	Sector/Industry/Product*
Not clear	Recycle	C2C	*organic, grounded
Circular economy (CE)	Reuse product/component	B2C	
Sharing economy (SE)	Remanufacture	B2B	
Collaborative consumption (CC)	B2C access	C2B	
Product-service system (PSS)	C2C access	End-of-Life	
	B2B access	More than one type	
Industrial ecology (IE)	More than one type	Not clear	
Industrial symbiosis (IS)	Not clear	Not specified	
Performance economy (PE)	Other		
Eco-industrial park (EIP)			

RESEARCH DESIGN

Publication type	Type of study	Research approach	Research method*	Data source
Journal article	Conceptual	Qualitative	Not clear	Primary
Conference paper	Empirical	Quantitative	More than one method	Secondary
Book	Literature review	Mixed-method	Case study	Primary and secondary
Book chapter	Systematic literature review	Theoretical analysis	Discourse analysis	Not clear
Special issue in a journal	Not clear	Not clear	Ethnography	
Popular science article			Focus group	
			Interviews	
			Survey	
			...	
			*organic, grounded	

BARRIERS IDENTIFICATION, CONTEXT

Barrier focus	Barrier identification	Level of analysis*	Geographic Context*	Country if specified*	Human development context
Barrier(s) are not the focus	Empirically identified by paper	Not clear	Not specified	Not specified	Not specified
Barrier(s) are the focus	Predefined/known/assumed	More than one level	More than one	More than one country	More than one type
No barrier is mentioned	Indirectly mentioned	Business model	Africa		Developing country (LMIC)
Not clear	No barrier is mentioned	City scale	Antartica		Developed country (MEDC)
	Identified through literature review	Governance/Policy	Asia	*organic, grounded	
	Not clear	Material flows	Europe		
Nr. barriers studied		Organisation	Middle East		
		Value network	North America		
One		Product/Technology/Design	Oceania/Australasia		
More than one		User/Individual	South America		
Not clear		...			
		*organic, grounded	*organic, grounded		

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*organic, grounded
Primary Secondary
Primary and secondary

2.4 Synthesis

The title, abstract and authors' keywords of the 527 publications were read and coded accordingly to the study coding strategy created. It took approximately two months to complete coding for all publications. Given the broad scope of the systematic map, individual articles were not appraised for quality at this stage (i.e detailed assessment of research design and study characteristics). Instead, appraisal was limited to assessing the overall confidence of the codes attributed to each publication, that is, the extent to which we were confident that the codes reflect the information contained in the full text. We used the statistical programming language R to analyse the data. The map was connected to RStudio using the package 'googlesheets'. The coded data were sorted and compiled into an interrogable database using the packages 'dplyr' and 'tidyr'. Visualisation of descriptive statistics was done using the package 'ggplot2' (Wickham 2009).

3. Results

3.1 Studies screening

One hundred forty (140) studies of the total 527 publications were excluded for not meeting the inclusion criteria such as topic was not related, out of focus, or barriers were not included. These were identified as false positives hence were excluded from further review. Worth noting is that among these publications there were a considerable number of studies that resulted as false positives due to the term 'limitation' being commonly used in abstracts and many journals use the term 'limitation' although not relating to the objective of this study. Further, seven papers were excluded because their abstract was not available and nine entries were identified as special issue reports. Thus, a total of 380 publications were coded and formed the map. The systematic map database is presented in a Google Drive spreadsheet and organised into all the developed categories where insights can be extracted.

3.2 Article publication trends

Over the last decade, there has been a steady rise in the number of articles published on barriers regarding circular economy, the sharing economy, collaborative consumption and product-service systems. Figure 2 shows the distribution of articles over time. A steep growth in the number of published articles can be seen between 2015-2019, with a total of 114 articles published in 2018. Numbers look different for 2019 given this was the time the mapping was being conducted, including publications only until January 23, 2019. Article publications in peer-reviewed journals are shown to be predominant and conference papers follow. A number of reviews can be noted as well in 2018, which show that the stream of research in CE, SE, CE, and PSS may be reaching more maturity stages where scholars synthesize work.

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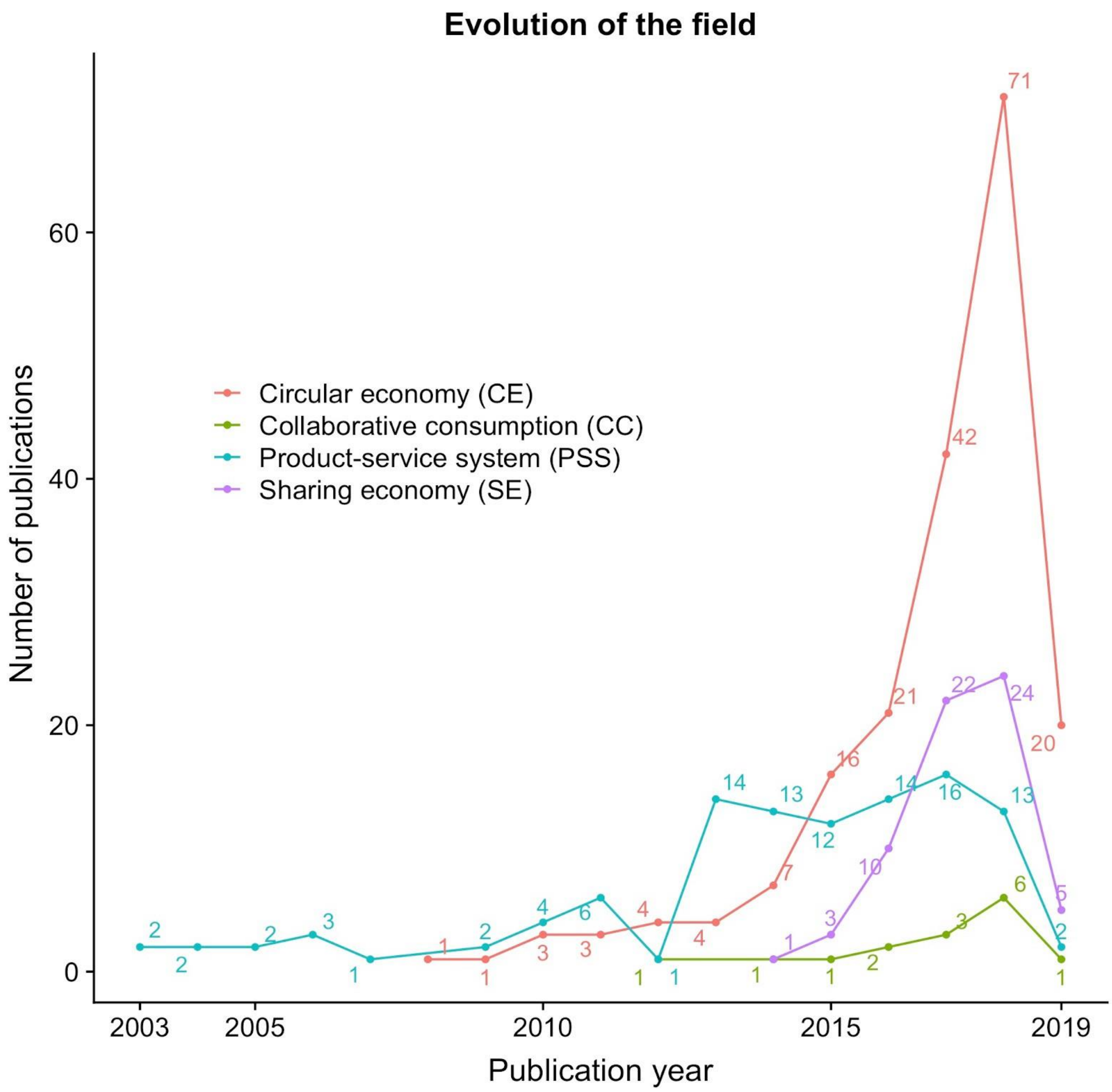

Figure 2.

Figure 3 below presents the spread of article publications in different sources. Notably, the Journal of Cleaner Production (n=44) has attracted major publications from the included publications. The following journals such as Sustainability (Switzerland) (n=18), Resources, Conservation, and Recycling (n=17) as well as Journal of Industrial Ecology (n=12). Meanwhile, for conferences, two channels seem to be of utmost relevance for publications, Procedia CIRP (n=28) and Proceedings of the International Engineering in Design (ICED) (n=7). The rest of publication channels contained less than five articles published hence are not shown in the figure. The distribution of publications is spread across a wide variety of channels demonstrating the variability of the research topics and areas of application in CE,SE, CC, or PSS.

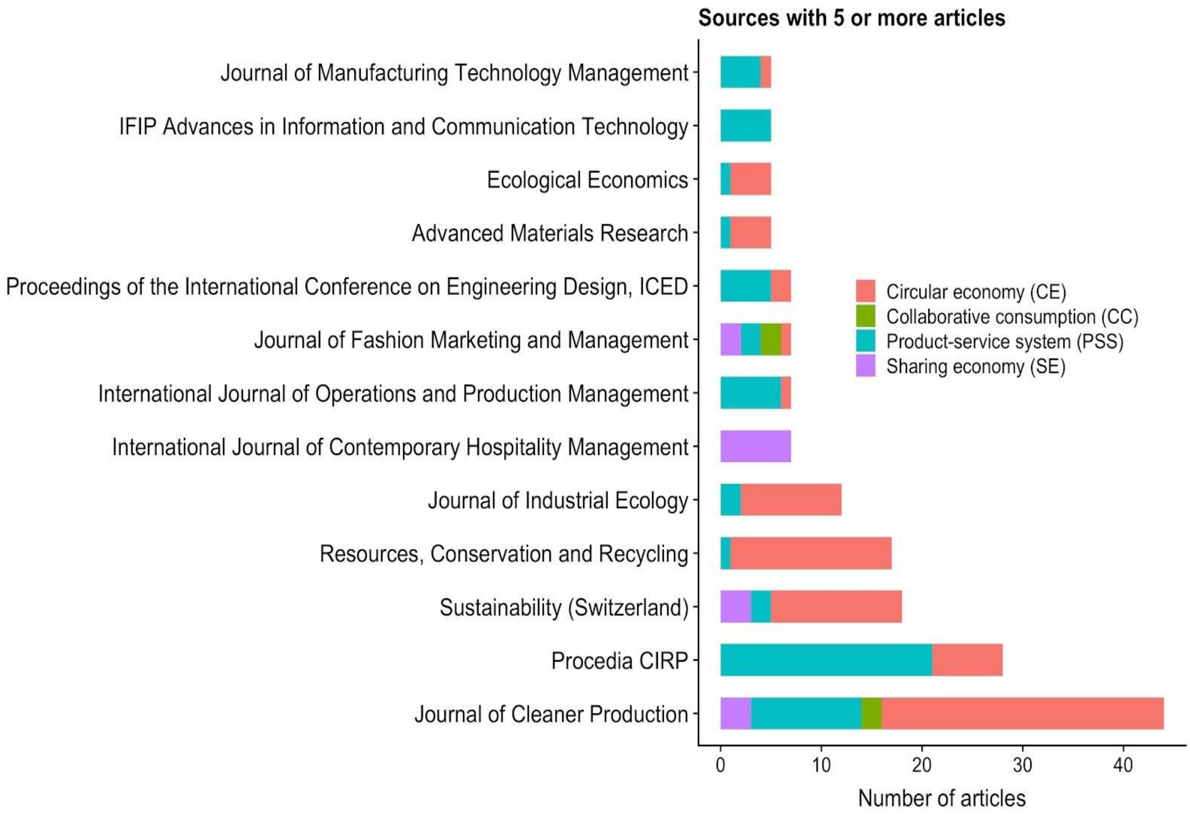

Figure 3.

Most popular channels for circular economy publications are Journal of Cleaner Production, Sustainability (Switzerland), and Resources, Conservation, and Recycling. For sharing economy, are Journal of Cleaner Production, Sustainability (Switzerland), and notably International Journal of Contemporary Hospitality Management. This can possibly be attributed to the popularity growth of shared accommodation platforms in tourism e.g. Airbnb. For product-service systems, majority of publications come from Procedia CIRP and Journal of Cleaner Production, while others scoring high are International Journal of Operations and Production Management, IFIP Advances in Information and Communication Technology, Journal of Manufacturing Technology Management and Proceedings of the International Engineering in Design (ICED). Studies on barriers from all the four domains seem to be most represented in engineering and technology science, and little in social studies such as consumer behavior, or cultural studies.

3.3 Dominant paradigms and loop strategies

As the mapping was in progress, six publications were classified as industrial symbiosis (IS), five classified as industrial ecology (IE); three classified as eco-industrial park (EIP), and one as performance economy (PE). These were then reviewed by the whole team and finally categorised as circular economy, given that they met the criteria of this category based on mutual agreement among the researchers. In Figure 4 below, we can distinguish the resulting dominant paradigm among the literature selected for abstract mapping of which 178 were classified as circular economy (CE). In the final mapping, CE dominates with a total of 193 (50.8%) publications followed by product-service systems (PSS) with 107 (28.2%). Third is the sharing economy (SE) with 65 (17.1%) publications, and last is collaborative consumption (CC) with 15 (3.9%) publications. These results may be attributed to that

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circular economy is a much broader strategy containing a wider complex application e.g. recycling, or remanufacturing, whereas product-service systems and sharing economy for example, are much more straight forward strategies. The other interpretation can be attributed that there are more challenges or barriers connected to the circular economy or that research in product service systems and sharing economy may have reached a more mature stage of implementation.

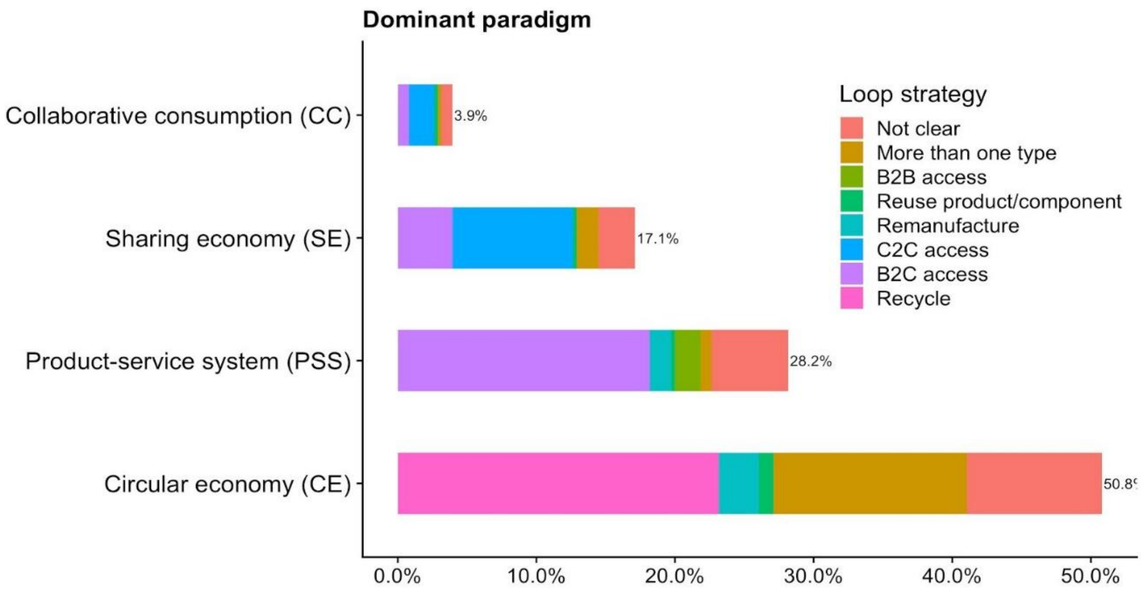

Figure 4.

Through this classification we distinguished between which paradigm is dominant in publications. Going further, it was possible to specify the spread of different loop strategies associated with each paradigm, shown in Figure 5 briefly and specified further in the Figure 4 below. For example, 'recycling' as a loop strategy is observed in 23.2% of the articles selected. Whereas, approaches such as remanufacturing, reusing (e.g. products, components, or materials) were observed less. Only 4.5% of papers contained remanufacturing and only 1.8% contained reusing as core strategies. These were associated in majority with the circular economy paradigm and product-service systems. However, a number of papers, although containing recycling, were not directly mentioning anyof the four paradigms, which could imply that if literature reviews are limited to the search based only on the larger paradigm concepts, then there can be underlying literature not being captured. 22.9% of papers addressed B2C access, the majority of which resides under the umbrella of product-service systems paradigm, and 10.5% concerned C2C access majority of which is listed under the sharing economy paradigm. Interestingly, only 1.8% of papers had B2B as main strategy and this was primarily in product-service systems.

Publications that addressed, for example, a B2C access strategy and were related to manufacturing, were classified as "more than one type of strategy". 16.6% of articles included for mapping contained more than one strategy and predominantly this was observed in papers under the circular economy paradigm or the sharing economy paradigm. Interestingly, 18.7% of papers were not clear in the type of strategy they addressed and this was prevalent among all the paradigms noted. One explanation is that the papers addressed generally the paradigms as a whole and not any particular subset or these were not specified in the abstracts. However, the lack of specification in cases where it could, may create further complexity in reaching literature conclusions. For example, a B2B remanufacturing approach can have a completely different supply chain compared to a B2C reusing approach.

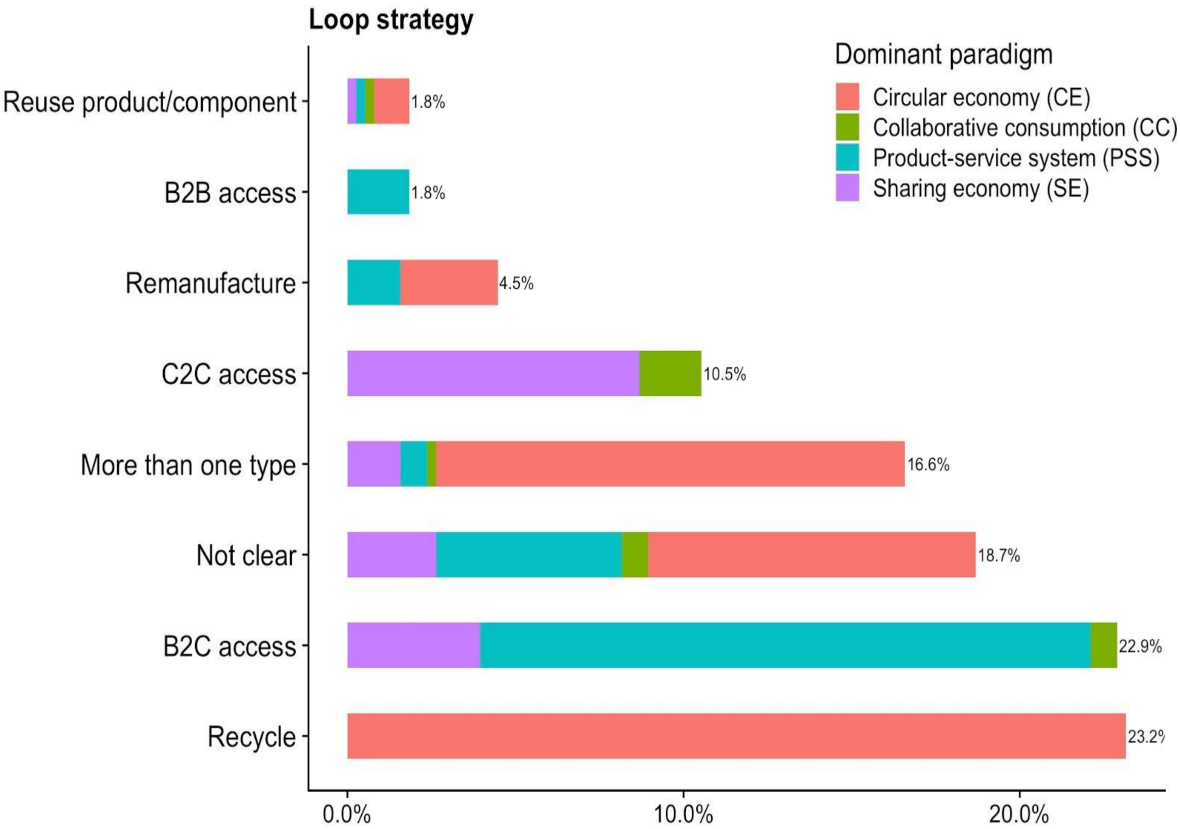

Figure 5.

3.4 Methods used by the studies

The research approach and type of studies in all abstracts screened is diverse and mixed methodologies seem to be widespread across the literature on all the four paradigms. Figure 6 shows that a qualitative research approach is the dominant one comprising 40.5% of studies, among which the majority of papers are empirical studies, followed by literature reviews. Only 12.9% of studies employ a quantitative research approach and these are predominantly empirical studies, whereas 10.8% of studies use a mixed-method approach also with a majority of articles being empirical studies. Interestingly, quantitative studies are considerably low among product-service systems favoring a more mixed method approach. However, in 23.9% of abstracts, the research approach was not clear or not directly implied hence we classified them through our own inference of type of study in which we distinguished between conceptual, empirical, literature reviews, reviews or not clear at all. Even so, inferring the methodological approach from the abstract was evidently unclear hence considerably affecting the mapping process and consequently the analysis.

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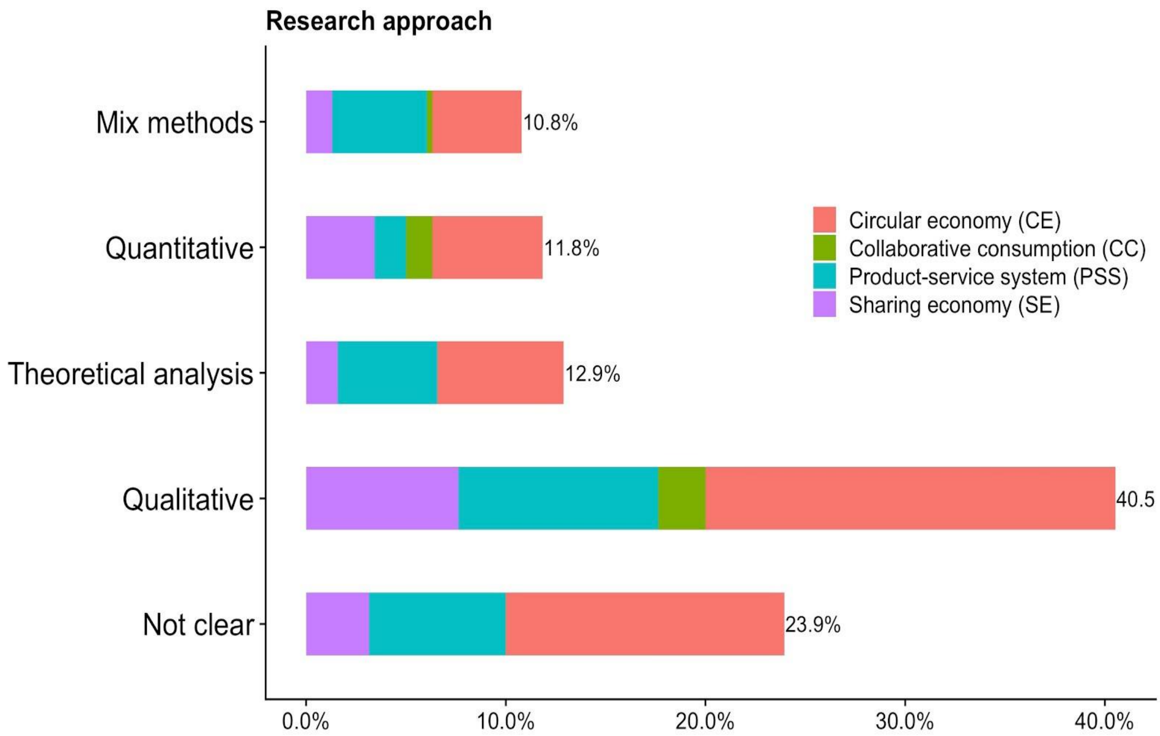

Figure 6.

Similarly, in terms of research methods used, Figure 7 shows 29.7% of abstracts lacked indicating the type of method used, hence were classified as not clear. This can create challenges for systematic mapping since lack of specification can jeopardise the selection process for further evaluation and analysis towards systematic literature reviews. On the other hand, in 14.2% of the abstracts, the research method employed is case study. In 11.1% of the abstracts, more than one method was used to conduct the study. Following are the literature reviews (8.9%), interviews (7.4%), surveys (7.1%) and other methods present among the literature (see further Figure 7). The results show that the majority of studies are case based, which can indicate that generalization of findings need to be taken with caution. In addition, this demonstrates the need for clear communication of the study approach, methodology, and methods in the abstracts relating to CE, SE, CC and PSS in order to enable better analysis of studies and their implications.

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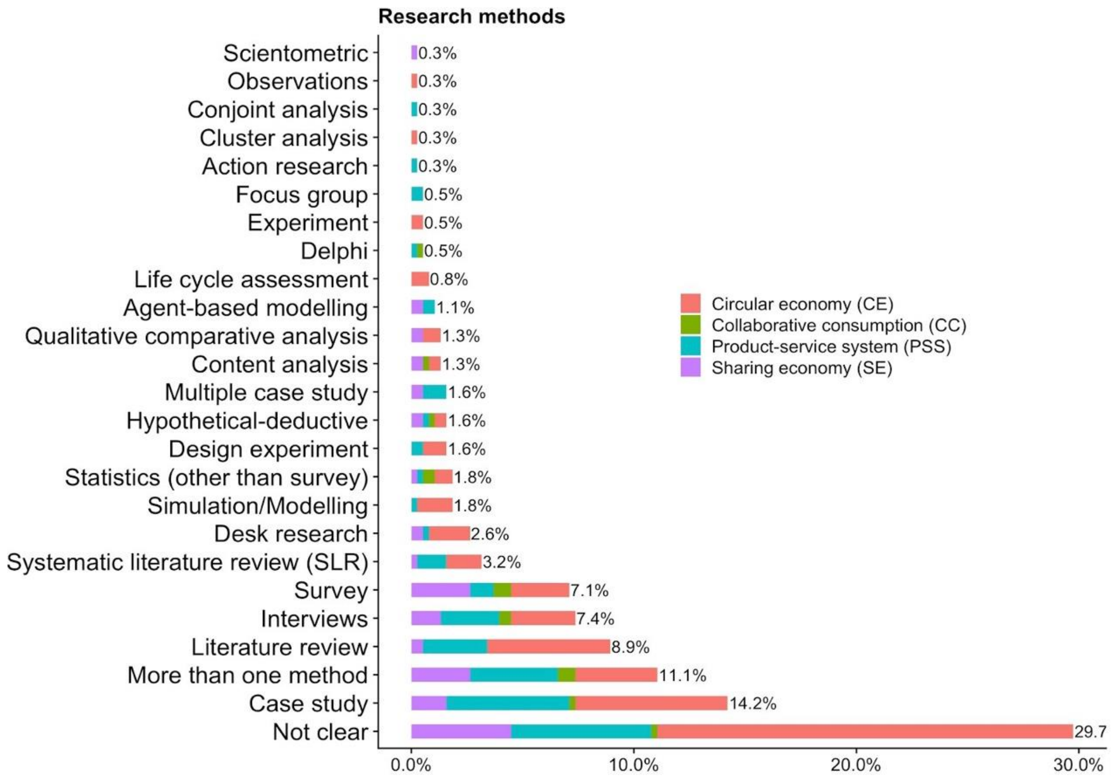

Figure 7.

3.5 Barriers identification

During the mapping process, the objective was to distinguish how are barriers understood and identified in literature, hence we classified between barriers being the core focus of publications and not directly the focus. As seen in Figure 8 below, 120 (31.6%) publications identified barriers empirically through case studies, or other qualitative and quantitative research methods. 89 (23.4%) publications however, identified barriers through assumptions, by generalising knowledge or based on predefined problems by other scholars. For example, many abstracts discussed the barrier of user acceptance towards a circular strategy and assumed that this is a true barrier while building the entire research design around this assumption which very few papers attempt to test through empirics or other approaches. In 66 (17.4%) publications, barriers were identified through literature reviews and this was either done through systematic literature reviews or background studies. In the majority of the publications, barriers were the main focus in relation to CE, PSS, SE or CC, however, regardless that the keyword search was specified to include only publications related to barriers, hinders, challenges alike, 84 (22.1%) abstracts did mention barriers but were not directly studying the barrier(s). After the mapping was complete, another 21 (5.5%) of publications were identified as not addressing any barrier perse although they contained the keywords. Similar pattern distribution can be observed also when we break down further the data and show all the subset strategies categorised within CE, SE, CC, and PSS.

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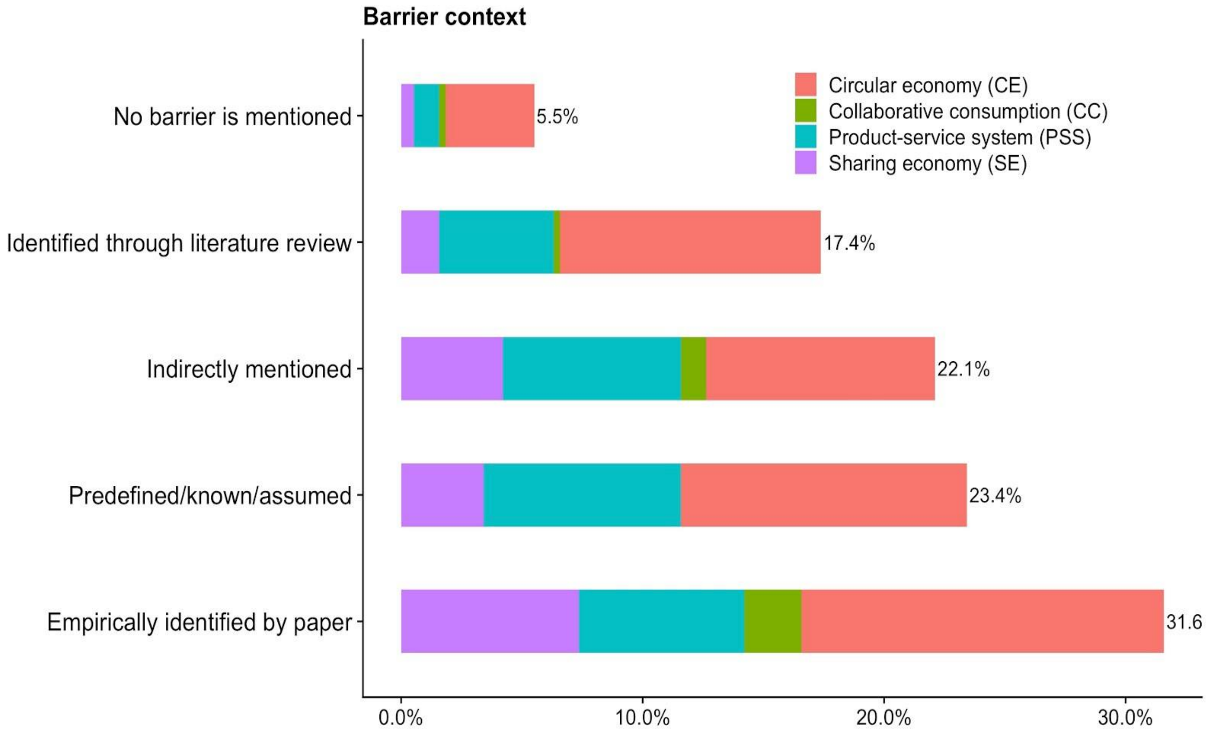

Figure 8.

3.6 Barriers context

In terms of context, we distinguished between levels of analysis, industrial sector/products, and geographical context in which the study took place. Figure 9 below shows that 24.2% of the abstracts discussed barriers in relation to more than one level of analysis or were difficult to classify into a category hence were classified as containing more than one analytical perspective. 15.5% of abstracts addressed barriers in relation to the business models. 13.2% of them addressed barriers in relation to the user or individual context such as consumer behavior, adoption, acceptance, or experiences with regards to CE, SE, PSS or CC regardless of what strategy the papers were addressing. 9.5% of abstracts were related to governance or policy together with another 9.5% relating to products, technologies, or design of these. The rest of abstracts addressed barriers in relation to the material flows (7.6%), organisational (6.6%), and value networks (5.5%), which were expected to be much higher initially given the complexity of organising for circular or sharing systems. However, these are possibly also assumed under the business model perspective since value networks, organisation, and material flows can be considered as part of the business models as well.

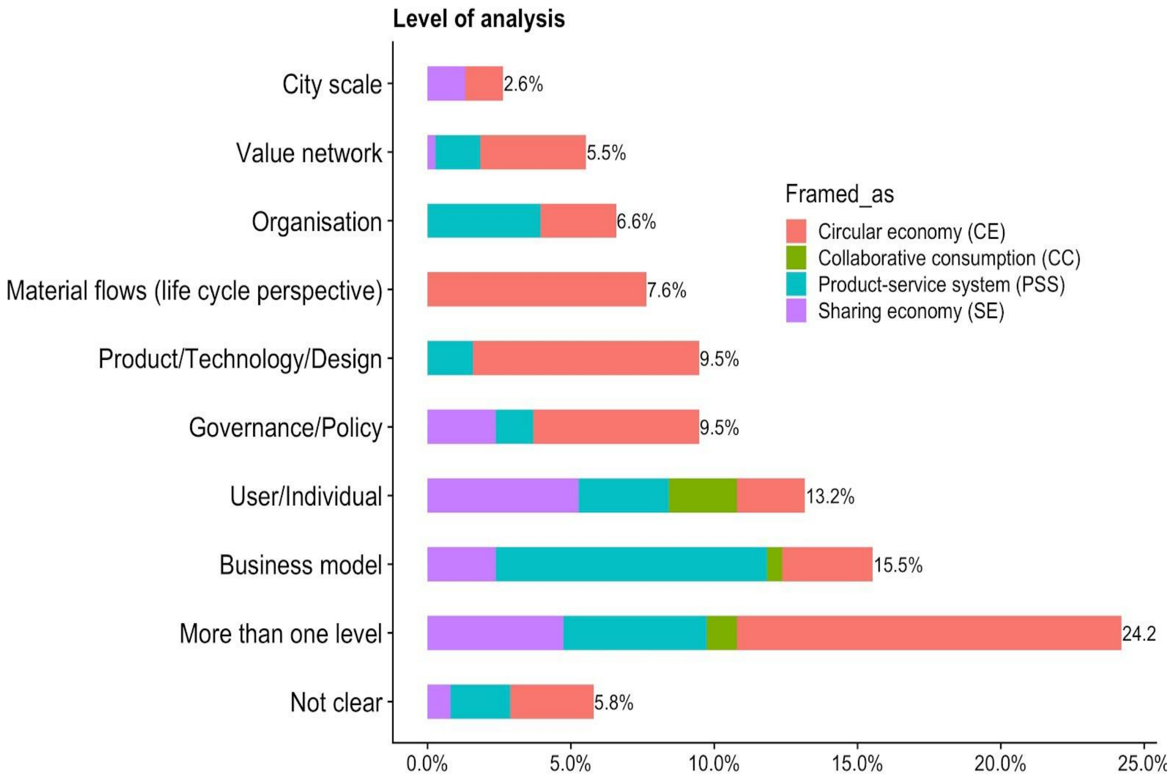

Figure 9.

Coding was also performed with regards to sectors, industry or product and this was a category that was organic as the reading proceeded due to the diverse nature of studies. The results show that circular economy, the sharing economy, and product-service systems are applied widespread in different sectors and industries. 18.4% of the abstracts are situated in or relate to the manufacturing and heavy industry; 7.4% in energy and infrastructure systems, followed by transport and mobility and others as shown in Figure 10 below. Even when coding for a specific industry such as mobility for example, studies differed between types of mobilities e.g. car sharing, bicycle sharing, public transport etc. 10.5% of the studies were situated or related to more than one type of sector, industry, or product. However, 28.9% of the articles were categorised as unclear, whereby the abstracts either did not mention the type of sector, industry, or product, or such specification was not possible due to the nature of the study. In most cases, the studies did not specify and we categorised them based on the interpretations of the content of the abstracts. This percentage is however high and may imply that studies although highly case based (as shown above) lack specification of the study approach making it challenging to explore barriers in industry- specific aspects or product-specific context. Another 10.5% of the abstracts were also categorised as ‘more than one type’ meaning they were cross-industry studies, combined sectors, or multiple products.

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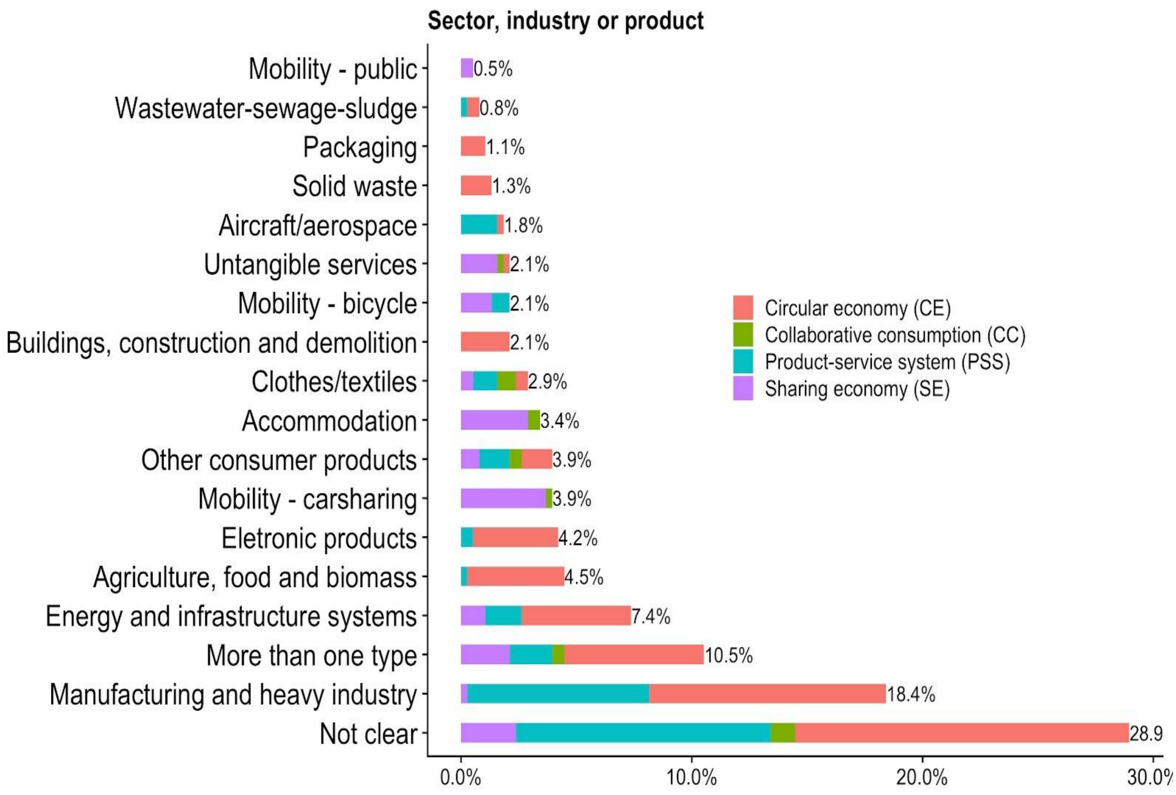

Figure 10.

In Figure 11 below, the spread of geographic context of studies is shown. 234 (61.1%) papers were classified as unspecified due to lack of data on the abstract inferring the geospatial setting of the study. The rest of papers which specified, 28 (7.4%) were conducted in China or contained data from China, 21 (5.5%) combined data from more than one country, with the remaining others who ranked less than 10 papers per country. Worth noting is that studies on PSS and CC rarely specify the geographic context. The interpretation however can be misleading if we rely only on the data from the abstracts, hence, these will be further verified with the full text reading.

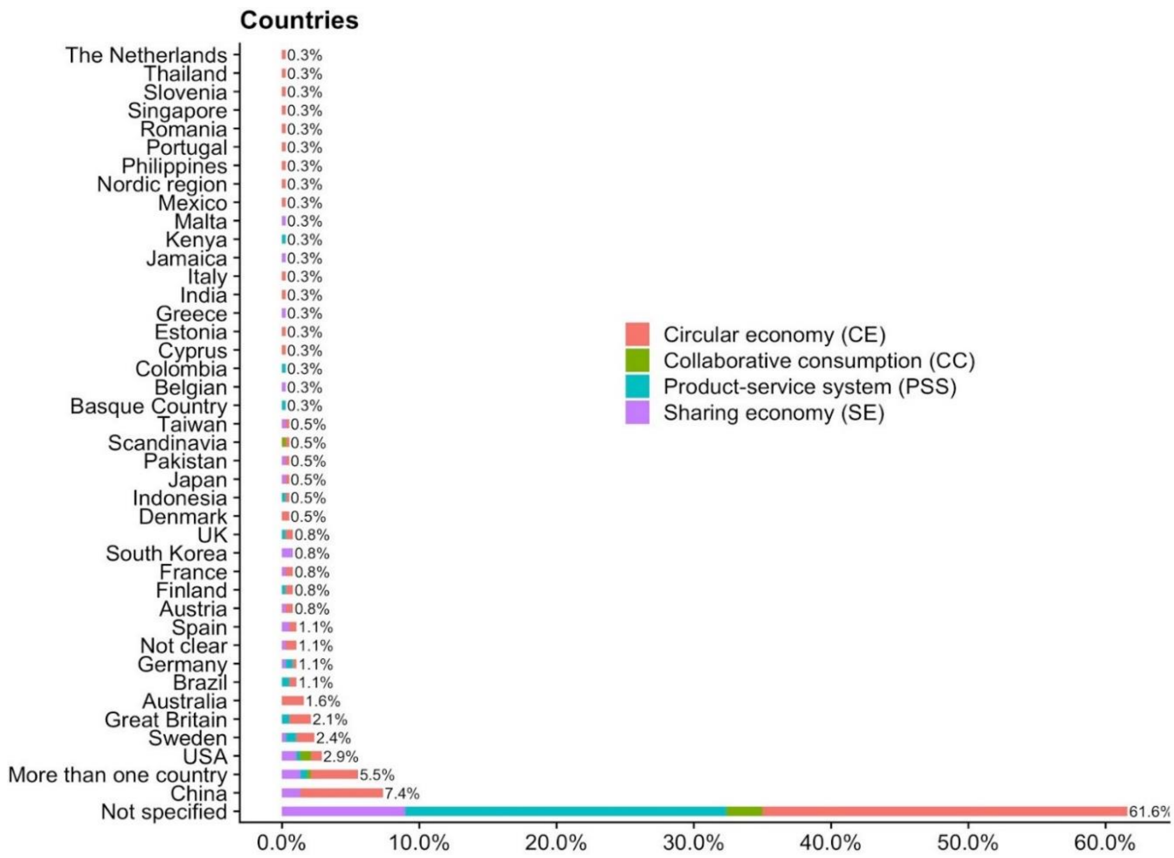

Figure 11.

4. Discussion

Numerous publications have spurred the body of literature about barriers and challenges for realising strategies such as CE, SE, CC, and PSS. In this paper, therefore, a systematic mapping was developed based on a classification system with the purpose to organise and consolidate research knowledge in order to analyze the progress in literature regarding barriers towards implementing CE, SE, CC and PSS. The study has compiled the largest synthesis of research articles documenting barriers to realising circular loops to date and is the first of its kind. It presents the collection classified in a fine level of granularity and in the format of a searchable database, taking a step ahead from previous systematic review efforts. The collection offers several general insights on the state-of-the-research concerning barriers where a few patterns are evident.

First, it shows the emergence of the paradigms circular economy and sharing economy in the context of realising circular strategies particularly in the last two years. Second, although the majority of publications were published in one journal (the Journal of Cleaner Production), there is a large spread across diverse publication channels and sources (journals and conferences). Though, the studies on barriers regarding the four paradigms are mostly represented in engineering and technology science journals and conferences, with less presence in social science such as consumer behavior or cultural studies among others. One explanation can be that the fields are just starting to enter the social realms in terms of applications reaching markets, or strategies being implemented in society. It should be taken with caution, since the channels where these studies are published contain also interdisciplinary studies which mesh technology and engineering with social behavior, organisational, or governance studies.

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In terms of the specific loop strategies, we found that barriers related to the circular economy paradigm dominate the publications among which particularly high is realising "recycling" as a circular loop; much higher than remanufacturing or reuse. This can be due to the recycling being a more established process in the industry, where more attention has been given. Further, it can also signal that other circular strategies are only now emerging, hence, fewer studies have been published with regards to barriers in their implementation.

However, a large proportion of studies addressed more than one circular loop especially in relation to CE and SE. The challenge in distinguishing studies in terms of the particular circular loop they address is evident when reviewing abstracts, hence inferring conclusions is rather difficult even when categories have been developed to classify them. This can lead to misinterpretations of conclusions if they are based only on the systematic mapping and reviewing of abstract, therefore further analysis is suggested. On the other hand, from the classification, we noted that barriers are predominantly addressed from a B2C point of view within the context of PSS strategies, or C2C access within the context of SE. Whereas interestingly, a very small fraction of papers discuss barriers in relation to B2B which is a surprise as we assumed this perspective would be addressed more, given that in theory, most circular strategies are linked with supply chains of materials, goods, and services; hence, we would assume barriers to be more evident in B2B contexts as well. On the other hand, this can also be interpreted that there is a potential research gap and opportunity to address further the inter-organisational challenges in relation to implementing CE, SE, and PSS.

Third, we also found a large variety of research methods being used and a dominance of qualitative research. The majority of studies that address barriers towards CE, SE, CC and PSS are qualitative case studies and interviews, which indicates that the field is still emerging and expanding. While at the same time, the analysis suggests that generalisation of findings need to be taken with caution particularly when studies are contextual. Moreover, a large percentage of abstracts was found difficult to classify with no clear research approach or not directly implied hence, we suggest the need for clear communication of the study approaches in scholarly work in order to improve quality assessment as well as enable better analysis when performing systematic reviews.

Furthermore, the findings suggest that the majority of the publications have identified barriers empirically through both qualitative and quantitative research approaches; though, a considerable proportion of the abstracts reviewed identify barriers through assuming that they exist, relating to known or predefined barriers by other scholars. These patterns could be observed even when we broke down further the categorised data and showed all the subset strategies within CE, SE, CC, and PSS. We particularly paid attention to the framing of research objectives and aims among the abstracts, wherein it became evident that further research on study validation, results verification and reproduction may be necessary as the fields progress.

When it comes to barriers context, almost all studies have addressed barriers in a mixed-fashion treating multiple levels of analysis, followed by papers focused more on business models, then user or individual context, governance and policy, and lastly, products and technologies or design. Interestingly, a small fraction of abstracts addressed barriers in relation to the material flows organizational, and value networks, which were expected to be much higher initially given the complexity of organising for circular or sharing systems. We are not sure whether these findings imply a hierarchy of barriers or if the research interest is largely connected towards businesses, hence further review of the full papers is necessary. A comprehensive systematic literature review derived from this mapping is in progress in a forthcoming paper. Nevertheless, the trend is clear that there is a highly interdisciplinary and cross-fertilisation of strategies, cases, methodologies, and empirics, whereas the industrial context is widespread across different sectors and industries in which studies take place. As discussed, the majority of the studies reviewed are case studies but clearly many lack specification of the study context, especially in terms of the industrial sector or geographical context, which makes it challenging to explore barriers in industry- specific aspects, business-specific context, or product-specific context among others.

Lastly, through these findings, we have identified salient gaps on how the context, sector, loop strategy and research method is reported in the abstract of publications. Our results are aligned with those of Tura et al. (2019) and Kirchherr et al. (2018) in showing that the studies on barriers have varied implications depending on contextual factors of the study in question. We suggest future scholarly work to delineate the context of studies especially when different contextual factors may come to perspective hence affecting the application of circular strategies. Future studies should make it explicit these and the other constructs developed in this research. This seems even more important when extracting solutions or propositions in papers, and a deepened study of barriers and solutions in contexts is needed.

Our classification framework allows for accumulation of knowledge which is particularly important to the consistency and maturity of the field. A clear typology and discrete typology is also relevant to policy-making and interventions. Finally, this systematic map should enable other researchers to rapidly locate and assess the state-of-the-research on barriers. It allows for the development of more focused systematic reviews (for instance for a specific paradigm, loop or sector). Our map provided a single snapshot of the existing research, but could become dynamic with periodic updating every 3–5 years.

Evidently, there are limitations with regards to such systematic mapping framework two of which were particularly critical. First, is developing solid categories for classifying the studies. A challenge among the research team was to have a common understanding of delineating for instance the industrial sectors and their boundaries given the diversity of studies. And second, is differentiating between the perspectives and lenses of the analysis in various studies even when a framework has been developed apriori. This because if a certain framework is developed apriori, it can jeopardise and exclude some studies based on its criteria; or, when organic categorisation is enabled, then numerous subcategories emerge creating challenges in clustering and generalising the results.

5. Conclusions

To date publications on barriers to realise circular strategies have neglected the importance of specifying the context in which the barriers reported were identifying. Hence, preceding studies have had weak basis to build further knowledge on past publications because the prominence of a specific barrier is directly affected by its context. Without a classification system for barriers and their context, isolated knowledge cannot cumulate. This paper aimed to address this gap by reviewing 527 on the topic and classifying them according to the specificities of their context. Studies were classified accordingly to their research paradigm (circular economy, the sharing economy, collaborative consumption and product-service systems), circular strategy (recycling, remanufacturing, component/product reuse, and utility-based non-ownership B2B/B2C/C2C access), country, sector/industry/product, and research approach and method. This system of typology can be used not only in

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future empirical investigation on barriers but also in more in-depth systematic literature reviews. Our analysis initially focused only on one side of the four dominant paradigms, by looking specifically from a perspective of barriers, obstacles, or challenges identified, conceptualised, and theorised regarding the implementation of CE, SE, CC and PSS, with a latter goal to identify solutions and mechanisms that address barriers.

Hence, further studies could contribute greatly by observing further which barriers, in which research paradigm, to which strategy, by which method they interact with various contexts such as geographic, industrial, socio-economic, and cultural contexts among others. We propose future research that focuses on further understanding of the interactions between barriers and the extent of complexity in addressing them through research, practice, and policy. This solid and consistent understanding of barriers can accelerate the development and implementation of mechanisms for overcoming them in the pursuit of circular production and consumption systems and sustainability.

Appendix 1: Practical screening protocol for abstracts review

Inclusion criteria	
Topic	Circular economy, Sharing economy, Collaborative Consumption, Product-service systems
Content	Must contain barrier/hinder/obstacle/inhibitor/limitation/hurdle
	Must relate to sustainability
Keywords	(TITLE-ABS-KEY ("circular economy" OR ("sustainable product service-system") OR "sharing economy" OR "collaborative consumption") AND TITLE-ABS-KEY (barrier OR hinder OR obstacle OR inhibitor OR limitation OR hurdle)) AND (LIMIT-TO (LANGUAGE , "English"))
Publication language	English only
Date of publication	No restrictions
Search engine	Scopus
Authors	No restrictions
Setting and context	Include all settings and map for our reference country/geography of study and context e.g. Place in value chain
Type of publication	Journal articles, conference publications, book chapters
Participants or subjects	No inclusion/exclusion on such criteria
Program or intervention	No inclusion/exclusion on such criteria
Research design	If the article is explicitly theoretical or conceptual, then exclude;
	If not explicit, then include for the second round of reading full article.
Type of study	All types of studies: empirical papers, research findings, qualitative and quantitative
Exclusion criteria	
Content	Out of focus: the publication content does not reflect with the objectives of the study
	False positives: publications that do not include barrier/hinder/obstacle/inhibitor/limitation/hurdle in the content
Topic	False positives: the main topic was not about circular economy, the sharing economy, collaborative consumption, product-service system
Technical	No abstract available
Type of study	Specific review articles (processed separately)
Type of publication	Reports, grey literature, books, or other non peer-reviewed
Type of study	Exclude conceptual articles, or without empirical data

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How can faba-bean cropping contribute to a more sustainable future European agriculture? - Analysis of transition opportunities & barriers in Denmark

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Abstract

The extensive use of soy-beans for fodder proteins within Denmark and the European Union in general are posing a serious environmental threat due to land-use changes and environmental degradation in South America countries, where a large part of the soy-bean is being cultivated. An agricultural system consisting of monoculture, primarily wheat being dominant in Denmark, and massive utilization of 'external' resources like artificial N, pest and weed chemicals, fossil fuels usage, etc. are constantly fed into the system to sustain it. To increase the domestic production of fodder proteins in Denmark, and to benefit from the many Eco System Services that legumes provide, this paper investigates how this can be achieves. By adapting Gells Socio-technical Transition (ST) theory on the Danish faba-bean production in a Multi-Level Perspective (MLP) - constituted by the 'landscape', 'regime' and 'niche' - an Analytical Framework is developed that facilitates an investigation of Transition Pathways' for Danish agriculture adapting to more legumes (faba-bean) for protein fodder instead of soy-bean import. The analysis reviles in which areas of the coherent (dominating) 'regime', that the Danish faba-bean 'niche' is challenging the existing 'socio-technical system'. We identify important Champions at the three levels analyzed and suggest that various activities are taken at all levels addressed to promote the cultivation of faba-beans. Emphasis should for example be given to strengthen local farm networks to share knowledge and farm equipment for intensified faba-bean cultivation, and use as animal fodder (niche). Besides this, university curriculum must be updated and increase farm advisors and farmer organization's knowledge of leguminous crops, as to improve their advisory tasks, and hence harvest as many environmental benefits as possible when cultivated legumes (landscape). Besides this, stronger environmental regulation must be applied to facilitate a higher uptake of e.g. faba-beans. This could be a reintroduction of the 'harmony rule' between size of the farmland and the number of livestock to facilitate an adequate area of arable farmland to become more self-sufficient in animal fodder (landscape). Seed and fodder companies could already now be more flexible to a changing 'regime', as they most likely would like to sustain their market shares, also in the future (regime).

Keywords: Faba-Beans, Protein Feed, Danish Farmers, Transition Pathways', Tradition/Culture.

1. Introduction

The demand for proteins has become a global challenge, which can be understood as a need for meeting the rising demand for proteins in the future by an increasing Earth population. According to Food and Agricultural Organization (FAO) under the United Nations (UN), countries in the developed world - including the EU and Denmark - are consuming unfavorable amounts of proteins, including fodder proteins, which are based on imports and the cause of environmental and social challenges (FAO, 2018). In combination with the expected population growth, increased consumption of meat, as a consequence of higher income of millions of people globally, it is tightening the pressure on the worlds' agriculture even further to provide both animal and plant proteins from unsustainable agricultural systems.

Therefore, there is a need to reduce the demand for traditional protein sources that require fodder proteins (less meat consumption), for limiting the import of proteins from unsustainable agricultural systems with long transportation distances (reduce import of soy-beans), and to become more self-sufficient in production of fodder proteins and legumes for human consumption that will provide ESS benefit within the EU (faba-beans, lupine, peas, lenses, etc.). This could provide a more circular agricultural system, where the drawing on 'external' resources is reduced, and 'internal' resources are valued higher and the subsequent environmental benefits etc. are being harvested.

Applying a more sustainable agricultural sector in Denmark is hampered by a reduction in the cultivation of legume based crops. Despite a policy focus within European countries to promote the cultivation of legumes, and a diversification of crops being produced, legume yields have declined during the last 10 years (Davis et. al., 2012; Lin, 2011). Over the last five decades the global average grain yield has almost doubled, but the cultivation of legumes dramatically declined. A 56 % decrease of for example faba-beans, has been observed (Jensen et. al., 2010). This is an unfavorable development for a future European, both on a local or a global scale, due to the many non-harvested benefits that legumes provide to our society.

This consequently means lower Eco System Services (ESS) provided by the cultivation of legumes, emphasized more below, as well as the need for intensified import of e.g. soy-beans from South American countries, often genetically modified spices (Nemecek, 2008), which is the cause of deforestation and the replacement of native people. Zander et. al. (2016) indicate that legume nitrogen (N)-fixation of between 130-153 kg N per ha can be achieved when cultivating such crops. Again, other research findings point to the same result, with variations between 100-200 kg N-fixation per ha (Jensen, et. al., 2010). Legumes also provide crop rotation services, which limit agrochemical costs by up to 25 % for e.g. cereals, and according to Zander et. al. (2016), leads to yield enhancement in the following crop by up to 0.2-1.6 t. per ha. The Eco System Services (ESS) of legumes are therefore highly devaluated for their contribution to establish a more sustainable, self-sufficient and diversified European agriculture.
15 Mt of soy-beans for protein fodder were imported by European countries in 2017, hereof large quantities from South America, second after China, with an import of 93 Mt in 2017. To put this in perspective Argentina, Brazil and the US produced 53 Mt, 87 Mt and 107 Mt soy-beans in 2017 respectively (LegValue, 2017a). Protein import for fodder in Denmark account for around 1.8 Mt annually, where 80 % is utilized for pig fodder, and the

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remaining as feed for dairy cattle, poultry and egg producing hens (IFRO, 2012; 2014). According to Forest Trends (2014) more than 7.2 M ha forest in South America, including the Northern part of Argentina - the country from where Denmark import the majority of its soy-beans - have disappeared between year 1995 and 2005. Natural and semi-natural habitats are consequently increasingly being converted into arable land, with severe impact on soil quality, climate change and biodiversity (Nemecek et. al., 2008).

1.1 Research aim

Environmental benefits, technical possibilities and policy suggestions for deploying more legume crops have been the focus of several European and international studies and are well described in the current literature (Nemecek et. al., 2008; Preissel et. al., 2015; Magrini et. al., 2016). This paper, however, seeks to provide knowledge that are required for the needed transition, with an emphasis on the Danish farmers' 'world', and the organizations etc. constituting the agricultural sphere's. We therefore intend to highlight how for example social embedded norms, cultures, traditions and values etc. provide challenges for a further uptake and cultivation of protein legumes - here faba-beans for animal fodder in Denmark - and which Transitions Pathways' could provide a be future direction. An analysis of important stakeholders in the existing 'regime', which constitutes Danish agriculture, will hence unfold the current 'socio-technical system' and its changeability (possible Transition Pathways').

The aim of this paper is therefore to a less extend to look at technical cultivation practices and options within Danish agriculture, but on cultural issues and traditions, where challenges and opportunities for increasing the production of faba-beans are emphasized. Providing such knowledge will facilitate ways to identify opportunities - Transition Pathways' - for the Danish faba-bean 'niche' to enter the current 'socio-technical system' and become a larger part of the existing 'regime'. This could provide more self-sufficiency in protein legume cultivation and create a more sustainable, diverse and resilient agriculture (Raseduzzaman and Jensen, 2017) based largely on 'internal' Danish/European resources.

2. Methods

In this section we elaborate on the Theoretical Framework chosen in this paper and the need for creating an Analytical Framework suited for this study. We will explain in which other research areas the Socio-technical Transition (ST) theory and Multi-Level Perspective (MLP) have been applied within recent research fields. The use of literature, selected case study and type of empirical data collection etc. will also be emphasis.

2.1 Theoretical Platform

Applying the Socio-technical Transition (ST) theory on the Danish faba-bean production in a Multi-Level Perspective (MLP), constituted by the 'landscape', 'regime' and 'niche' (Geels, 2002; 2011), we develop an Analytical Framework that assists our investigation of Transition Pathways' for Danish agriculture adapting to more legumes (faba-bean) cultivated for use as protein fodder. The analysis reviles in which areas of the coherent (dominating) 'regime', that the Danish faba-bean 'niche' is challenging the existing 'socio-technical system', where we mainly emphasize on existing traditions and cultures.

In the Theoretical Framework (Section 2.3) input to Geels' (2002) MLP are provided, by adopting our empirical data into the model of transition, where emphasis is on the most important stakeholders in the 'regime' - the Champions (Heves and Lyons, 2008) - and we hence problematize how the emerging of faba-bean cultivation clash and challenge existing practices embedded in agricultural traditions, cultures and norms. We also look at the challenges connected to current agricultural and environmental policies applied in Denmark. Suggestions for activities in the Danish faba-bean 'niche', and initiatives at the 'landscape' level are hence provided, as possible Transition Pathways' supporting a further deployment of faba-bean cultivation in Denmark.

Socio-technical Transition (ST) and MLP - in brood Transition theory - have been utilized to understand transitions to more sustainable systems within for example the transportation sector in Sweden (Fallde and Eklund, 2015), and the deployment of biogas technology within the existing energy supply (Olsson and Fallden, 2015). Transformation of large energy systems have been investigated by Lybæk et. al. (2012), who analyzed and compared the Kalundborg Symbiosis to Industrial Clusters in developing countries. Changes initiated by new business model have further been studies by Bidmon and Knap (2018), also applying the Transition theory.

2.2 The studied case: Faba-bean farmers in Denmark

In the following our approach to the Danish farm case study are explained, as well as other relevant data collections methods and analytical choices.

2.2.1 Case study (farmers interviewed)

In a period of two month during November/ December 2017 and January 2018 we visited and interview eight case farmers located in the three main parts of Denmark, namely Jutland, Funen and Zealand. The farmers were organic crop farmers, conservation agriculture crop farmers, as well as organic livestock farmers. All farmers, except one, cultivated - or had recently cultivated - faba-beans, as well as grass clover. Case study farmers hence represents a part of the Danish faba-bean 'niche', which are front runners and important stakeholders in disseminating a further cultivation of faba-beans. The case study interview form, were characterized by a semi-structured approach, with room for narratives that made us better understand the farmers 'world' and the sphere he or she is navigating within (Kvale, 2002; Yin, 2013).

In total 1½ to 2 hours recorded interviews, including field, stables, barn and machine house visits, were conducted at each farm, with a focus on farm history, type of farm, cultivation practices, barriers and possibilities for increasing faba-bean cultivation, values and traditions connected to current farm practices and choices taken, value chains, institutional barriers, regulatory framework conditions, changes needed to support the cultivation of legumes, and future plans. The recorded interviews were fully transcribed and a short condensate was elaborated from each transcription, with extraction of data and knowledge of the above. The qualitative farm data retrieved from the case study interviews is hence utilized to describe the Socio-technical System of Danish agriculture - the 'regime' - and to provide data for necessary initiatives at the ''niche' and'landscape' level to provide suggestions for future Transition Pathways' enhancing the faba-bean cultivation in Denmark.

2.2.2 Other types of data retrieval

Besides the data collection described above this paper also utilizes statistical data and policy information data

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from e.g. Danish public authorities, and background reports from LegValue publications, as well as materials from organizations like FAO, WRI, etc. Data on faba-beans and legumes in general - technical systems, cultivation practices, ESS, EU policy support schemes etc. - are retrieved from scientific publications by means of journal articles. Having elaborated on the data collection in this paper, we now turn to a description of the Theoretical Framework chosen for this study in the section below.

2.3 Theoretical Framework

Socio-technical Transition (ST) emerged, according to Elzen et. al. (2004) and Schot and Geels (2008) from several other theories and was developed to better understand complex multi-faceted transition processes, which became a need in previous decades. The perception of ST is to understand the conditions for changes - transitions - as being part of three analytical levels, which Geels (2002) call Multi-Level Perspective (MLP). Figure 1 below shows the MLP on transitions developed by Geels (2002). In the following, we will shortly describe this theory on transition, and at the end of the section operationalize it through an Analytical Platform for the present study.

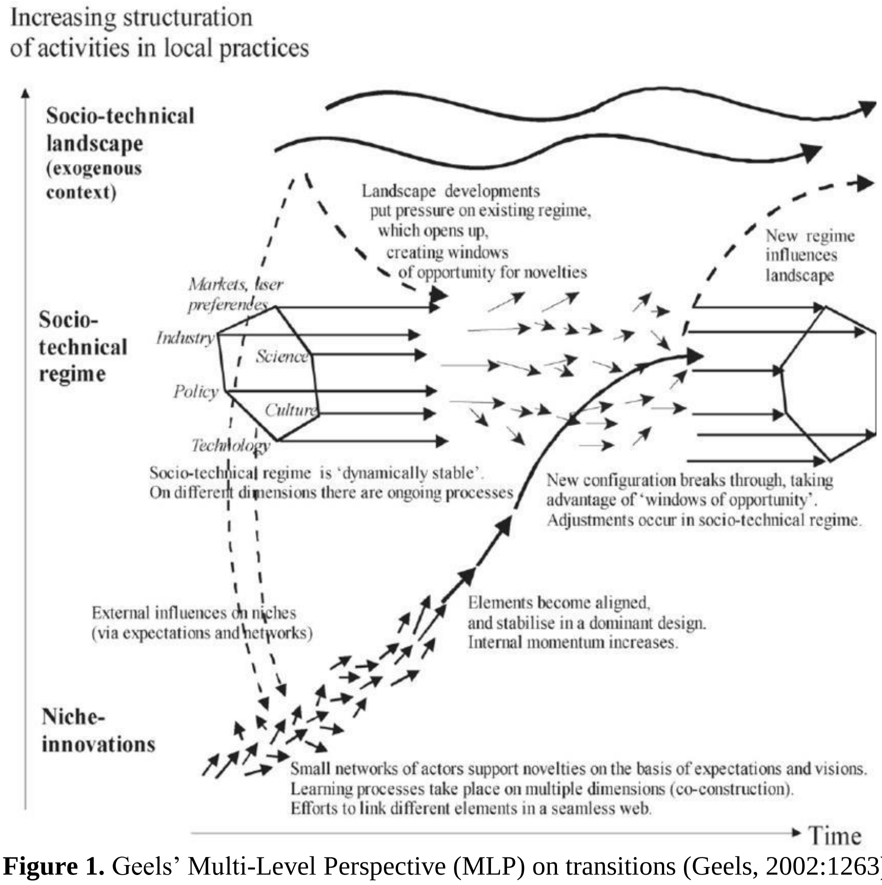

Figure 1. Geels' Multi-Level Perspective (MLP) on transitions (Geels, 2002:1263)

Starting from below, the first level is the 'niche' where radical and new innovations and novelties, e.g. products, systems and ideas, etc., are emerging and 'build up internal momentum' (Schot and Geels, 2008:545), that can impact and change - cause 'destabilization' (Schot and Geels, 2008:545) - at the second level being the 'socio-technical regime', which is constituted by already established institutions, practices, norms and culture, etc. in society. The third level is the 'landscape', which is external conditions, that will 'create pressure on the regime' (Schot and Geels, 2008:545), and again, possibly influence the 'niche' development.

'Niches' can play different roles, as they can become either a part of the dominating 'regime' or simply replace or substitute the existing system; thus, two types of co-evolution patterns can emerge. According to Shot and Geels (2008) the focus should however be on how niches emerges and contribute to changes in behavior, practices and routines, etc. of stakeholders in the existing regime. Depending on the findings, relevant suggestions for future Transition Pathways' will be proposed. The Multi-Level Perspective (MLP) on transitions is not a linear system of innovation and transitions, but must be understood as constant and dynamic loops between the three levels providing societal change (Geels, 2002). Through pressure, reactions and adaptation of niche innovations, that enters the existing regime, new 'windows of opportunities' (Schot and Geels, 2008:545) are created and transition possibilities emerge through the creation of a new 'socio-technical regime'. According to Schot and Geels (2008) transitions are therefore created as co-evolutions at all three levels, requiring that niche innovations link up with upper levels, and reinforces each other, to provide a constant pressure and ongoing processes at the 'regime' and 'landscape level' (Ibid.).

Different kinds of stakeholders and social groups constitute the three different levels, which can impact - work for or against - new transitions through e.g. dialogue, networks, regulation, economic subsidies, research (Geels, 2011). Important stakeholders with power to influence the three levels have in the literature been named for example 'Super-structures' (Vernay et. al., 2012) and 'Champions' (Heves and Lyons, 2008). These stakeholders are important actors in the development of or maintaining the coherent 'socio-technical system' (Geels, 2011). Novelties provided by stakeholders in the 'niche' can therefore find it difficult to penetrate this coherent system, as it can be constituted by stakeholders' lock-in, within an existing and stable 'regime', by means of various institutions, organizations, economics and culture's, etc. According to Geels (2004) the work conducted in 'niches' is however very important, as being the actual root for changes in society.

2.4 Analytical Framework

Having shortly outlined Geels ST-theory above, we will provide an Analytical Framework for this study by operationalizing the theory on our case study, which will facilitate the platform for further investigations in this paper. In the Results and Discussion part (Section 3), we will highlight in which areas of the coherent 'regime', that the Danish faba-bean 'niche' actually challenges the existing 'socio-technical system'. Here, we will mainly focus on traditions and cultures, as mentioned earlier. In the section below, we will first provide input to Geels' MLP by adopting our empirical data into the model of transition, looking at the 'Danish faba-bean niche' in the MLP; 'landscape', 'regime', 'niche', and identify important stakeholders within the three levels:

Level one: Landscape

The agricultural 'landscape' in Denmark have over the years provided pressure on the 'regime' by e.g. dynamic and changing Danish and EU policies, required various changes in the coherent system. Changing export strategies and world prices on crop and meat have for example dominated the 'landscape', and has been an important part of how the existing 'socio-technical-system' in Denmark, especially toward the intensified monoculture and industrialization of the agricultural sector. New policies, knowledge and values constantly impact the 'landscape' and potentially penetrate down to the 'regime' and influence it - strongly or weakly - which provide a pressure on the 'regime' to adapt to changes and hence to undergo transitions.

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Important stakeholders at the 'landscape' level is e.g. Danish and EU policies, feed industry, farm advisors, farmers organizations, seed producers, national and international environmental organization, e.g. World Resource Institute (WRI), consumer interest organizations (NGO's) and organizations under UN, like the Food and Agricultural Organization (FAO) and the International Panel on Climate Change (IPCC).

Level two: Regime

The dominating agricultural 'socio-technical-system' in Denmark is largely characterized by self-sufficiency in cereals and a massive import of soy-beans, which have consequences in terms of costs and environmental impact. This monoculture cropping system has led to high yields, but lower resilience towards environmental perturbations and biotic stresses (Raseduzzaman and Jensen, 2017). Thus, the industrialized - largely cereal based agricultural system - is heavily dependent on import of 'external' resources to the system, as for example chemicals for pest and weed treatment, N to provide soil fertility, high amounts of fossil fuels to operate machinery, and utilization of protein fodder from abroad (Jensen, et. al., 2010). The livestock sector in Denmark is huge compared to the size of the country and is constituted of for example 20 M slaughter pigs per year, as well as a large dairy cattle sector, requiring high quantities of fodder proteins. The majority of the soy-beans are, as mentioned earlier, used within the intensive pig production.

Important stakeholders in the 'regime' level are conventional crop farmers and livestock farmers, feed industry, farm advisors, farmer organizations, farm networks (erfa groups), seed producers, etc. Current agricultural and environmental policies within the agricultural sector, are also pivotal for the existing coherent 'socio-technical system'. Technologies adapted in the agricultural sector, and the type of research funded and conducted, is likewise important for shaping the 'regime' (see Figure 1 above).

Level three: Niche

15.000 ha of faba-bean were cultivated in Denmark in 2017, which increased to 25.000 ha in 2018, equal to a yield of approximately 150.000 ton (six t. per ha.), and substituted 1,6 % of the imported soy-bean utilized as fodder for slaughter pigs, dairy cattle, poultry and egg producing hens (SEGES, 2019). Within the EU an estimated 575.000 ha farmland were cultivated with faba-beans in 2017 (LegValue, 2017b) corresponding to a yield of between 1.150.000 t. and 2.875.000 ton (yield variations between two and five t. per ha). Most protein feed are thus imported, as emphasized earlier in the introduction. Few Danish farmers - mostly organic crop farmers and organic livestock farmers - constitute the 'faba-bean niche' in Denmark, and cultivates this legume for own consumption or for sale to other farmers or to the feed industry. A few farmers apply the 'conservation agriculture' approach to farming in their cultivation of faba-beans, with limited work on the soil as a consequence. Knowledge of faba-beans has until now been concentrated on a few number of species and crop management strategies.

Important stakeholders in the 'niche' level are organic crop farmers and livestock farmers, feed industry, farm advisors, farmer organizations, local farm networks, seed producers and neighboring farmers in local communities, etc. Research conducted by e.g. universities and experimental trials done by farmers organization are important knowledge at the 'niche' level, where learning processes takes place and support a further dissemination of legume novelties.

3. Results and Discussion

With takeoff in the Analytical Framework developed above, this section will highlight which traditions and cultures are being challenged when Danish farmers cultivate faba-beans. We identify the most important stakeholders in the 'regime' - the Champions - and problematize how the emerging of faba-bean cultivation clash and challenge with existing practices embedded in agricultural traditions, cultures and norms, as well as challenges connected to current agricultural and environmental policies. Suggestions for activities within the Danish faba-bean 'niche', and initiatives in the 'landscape' - supporting a further deployment of faba-bean cultivation in Denmark in the current 'regime' - will be provided in the section to follow, as a discussion of possible Transition Pathways'.

3.1 Challenges of faba-bean production in Denmark

The data below are, where nothing else is indicated, provided by the farm case study - interviews and visits - as describes in the methodology section.

3.1.1 Outline of traditions and cultures etc. challenged by faba-bean production

i) Conventional crop farmers

Many conventional crop farmers reject cultivating faba-beans as they believe the field to be ugly, and not as beautiful as a mature yellow cereal field. Faba-bean fields are black at the final stage before harvesting, and some farmers even think that the field has been burned. Many conventional farmers are therefore reluctant to cultivate faba-beans, as they do not look 'right'. Besides this, many farmers believe that faba-beans is winter beans only, and must be harvested during winter, and that the harvesting process it selves is difficult, and the machinery gets dirty and is difficult to clean. There is also an interpretation that faba-beans are difficult to treat for pests and weeds, compared to other crops. When harvesting faba-beans the weather is regarded as important, as wet harvested beans require drying capacity at the farm, and some farmers will therefore be challenges by lack of drying facilities.

ii) Conventional livestock farmers

Questions are raised regarding the nutrition value of faba-beans for livestock fodder (amino-composition), and whether traditional protein sources like soy-beans can be completely or partly substituted. Insecurity of the quality and composition of the fodder mix, when using faba-beans as animal feed, therefore exists. The content of bitter tannin in the shell of the bean, which must be removed by toasting - when used as dairy cattle fodder, but not necessarily as pig fodder - is regarded as challenging process, as new machinery (toaster, grinder, dryer, etc.) must be purchased, and storage capacity for treated faba-beans must be established.

As far as storage capacity there is no tradition for large storage capacity on Danish farms, as conventional protein fodder as soy-beans normally will be delivered in small batches, for instance every second week, requiring minimal storage capacity at the livestock farm. Unless the farmer has available space, it is necessary to build additional farm barns when converting from conventional protein fodder to legume based protein fodder, as faba-beans.

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iii) Feed industry

Conventional Danish agriculture is constituted by a tight dependency between feed industry and farmers, where little farm autonomy is identified regarding the supply of fodder. Internal trade between conventional farmers and other sorts of trade or sharing is relatively limited. The feed industry is therefore an important stakeholder - a Champion - in the supply of fodder in Denmark, and a log-in is identified with emphasis mainly on soy-bean as animal fodder. For the fodder industry it is convenient, that feed compounds come from large-scale overseas sources in large and homogeneous batches (Sauermann, 2009). Thus, organic crop farmers cultivating faba-beans experience a reluctance by the fodder industry, towards a penetration of alternative fodder produce into the regime, by relatively low purchase prices, high requirement in cleanness (dirt and soil) and dryness (moisture percentage) of the faba-bean delivered to them.

The feed industry's advantages of supplying soy-bean to farmers in smaller batches, has made investments in barn infrastructure and technical equipment, unnecessary at the farm level, as mentioned earlier. Purchase agreements between farmers and fodder companies can be made six to nine month ahead, providing farmers with a clear knowledge of fodder expenses, and security of supply. Prices and supply of faba-beans from the fodder company has, so far, been more unstable compared to soy-beans.

The 'niche'-cultivation of faba-beans in Denmark, and the identified emerging internal trade between organic crop and livestock farmers in local communities - being economically beneficial for both parties - is inconvenient and breaks with the 'monopoly', which the fodder industry have possesses for decades. The fodder industry is reluctant to embrace the new fodder produce entering the market and have only little interest in new types of internal protein trade between farmers. Their business culture mostly builds upon import of soy-beans, and the 'sunk' traditions in the current business model, is not easily changed. To have some sort of role in the supply of faba-beans in Denmark, they, however, purchase faba-beans - as farmers indicate to a relatively low price - and sell them on the fodder market. Hence, the reluctance of the fodder industry to provide large amount of faba-beans to conventional and organic farmers in Denmark, hampers a further deployment of legumes fodder within the 'regime' it selves.

iv) Seed producers

Seed producers in Denmark has to a minor extended focused their work on refining faba-bean spices favorable for the Danish climate and environment. Organic crop and livestock farmers cultivating faba-beans hence request more development in faba-bean cultivars adapted to the Danish context. The common understanding within conventional agriculture is that faba-bean spices are inappropriate in Denmark, need to be challenged. The most commonly spices utilized is Fuego, which is a tall crop easy to clean between the rows. Seed producers are Champions in the sense that good cultivars adapted to the local Danish context is important, just as the marketing of these spices. The market for faba-been seed is however not regarded as large, which impact the resources put in developing good cultivars by the seed producers. So, resources put is developing cultivars, which potentially only will constitute a small market, challenge seed producer in their interest in faba-beans.

v) Farm advisors

Farm advisors (consultants) are very traditional in their advices to farmers, when it comes to crop cultivation and the use of fodder proteins. The embedded values of traditional pest and weed control, use of fertilizers and other chemicals are strongly coupled to the monoculture, which Danish agriculture mainly is composed of. Applying organic farming with extensive crop rotation, legumes for N-fixation, and cultivation of cover crops etc., are not regarded as convenient as conventional farming. Farm advisors are not 'schooled' with the culture of seeing farming as a circular system relying on 'internal' resources, but as a system drawing extensively on 'external' resources. Noted by Magrini et. al. (2016) is that farm advices on crop rotation and diversification, is much more complex that the use of traditional chemicals, leading to a farm advisory system not even considering these benefits, including ESS. Thus, farm advisors are Champions shaping the discourse and direction of Danish farming and are highly challenged by other means of farm practices.

vi) Farmer organizations

Farmer organization (farmers umbrella organization) in Denmark are, as the farm advisors, part of the existing agricultural 'regime', and thus supports the conventional systems. A small sub-branch of the organization is however working to support or facilitate farmers cultivating e.g. faba-beans, lupines. They publish on web and print good stories of legume cultivation, etc. Farm tests of legume crop cultivation and the nutrition value of legumes, hereunder faba-beans, are exercised within this branch, but the majority of the research and activities are connected to conventional farming; e.g. pest control, optimization of crop yield and fodder plans, etc. Farmer organization employs thousands of people that work within the dominating paradigm of Danish agriculture and are therefore a strong Champion. The organization at a large is therefore challenged by the faba-bean niches emerging even though initiative to support it is a - although minor - part of the organization it selves.

vii) Farm network

Historically, farm networks (small local farm groups exchanging knowledge etc.) has been important institutions in Denmark, providing a platform for knowledge sharing, social activities and a cultural heritage and platform. With the role of farm advisors and farm sizes being increasingly larger and more autonomous in nature, the role of farm network within conventional farming in local communities has decreased. For organic 'niche' farmers cultivating legumes for animal fodder etc., farm networks however still play an important role for knowledge sharing, regarding for example the cultivation of legumes, legume fodder plans, protein contents and pre-treatment of legumes (drying, toasting), etc. With the absent of farmer organization and farm advisors focusing on these issues, the importance of the 'niche' farm networks increases correspondingly. Danish farm culture is increasingly becoming autonomous, as mentioned before, making it pivotal for faba-bean 'niche' farmers to utilize and mobilizes these networks. Thus, farm network activities within agricultural farming - sharing best practices within between each other regarding legume cultivation and fodder utilization etc. - are important and can be the sole source of valuable knowledge, which must be disseminated within the networks, and consequently also to conventional farmers networks within the 'regime'.

3.1.2 Current policies challenging faba-bean production

Current agricultural and environmental policies within the agricultural 'regime', are also pivotal for shaping the existent coherent 'socio-technical system'. As the focus of this paper manly is on analysis and discussion of traditions and culture within Danish agricultural sphere, and the stakeholders being challenge by the penetration of faba-bean cultivation, we will only provide a few inputs to this issue in the following.

i) Agricultural policy

Lack of agricultural farmland, through the termination of the 'harmony rule' requiring a balance between arable land and the amount of livestock animals, hampers Danish faba-bean farmers to increase their self-sufficiency in protein fodder. Thus, large livestock farms exist without adequate farmland to supply fodder. Many farmers

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therefore find it attractive to purchase soy-beans from fodder companies, as they might also lack storage facilities and find it difficult to deals with faba-bean proteins. Thus, the regulatory framework provides a challenge for farmers wanting to increase their legume farm area or/and be self-sufficient with legumes as animal fodder.

ii) Environmental policy

Increase in the utilization of N fertilizers on Danish farmland has been further liberalized - with the 2016 governmental farm-package - despite many environmental concerns, and the allowed amount of N provided to the farmland was thus increased with 50.000-60.000 t. per year. To compensate for this, EU required Danish farmers should cultivate more cover crops catching nitrogen to avoid environmental pollution of the water environment and ground water resources. Higher levels of N also mean more use of chemical etc., as increasing protein levels in e.g. wheat also intensify the pressure from pests and weeds. This regulatory framework does not support the growing of faba-beans and legumes in general, as a source of nitrogen supply to farmland. It, on the contrarily, strengthen the discourse of the 'regime' and supports the monoculture-based agriculture, which are dependent on 'external' resources. Lower levels of artificial N fertilizer provided to the soil, and thus a paradigm shift in the regulatory framework conditions, could increase the cultivation of legumes for N-fixation, and provide a more sustainable agriculture.

3.2 Discussion of Transition Pathways'

In the following section possible Transition Pathways' for adapting to more faba-bean cultivation and utilization in a Danish context will be outlined on the basis of the previous Results and Discussion in Section 3.1.1 and 3.1.2. Possible 'landscape' and 'niche' activities and pressure are identified for Transition Pathways' that can provide 'windows of opportunities' within the dominating 'regime' for transition of 'the socio-technical system'.

3.2.1 Transition Pathways'

When looking at conventional crop farmers more information and knowledge transfer are needed from farmers successfully working with faba-beans, as far as cultivation systems and practices, fodder quality, pest and weed control, etc. in order to increase awareness and break down myth of faba-bean cultivation. For conventional livestock farmers the question of knowledge transfer, as well as increased cooperation, is the main issue. Therefore, knowledge about the nutritional value of faba-beans and fodder mixes must increase, and farmers must increasingly share storage capacity and new types of farm equipment. New farms could also be established with storage capacity for fodder legumes, when planning the farm buildings in the future. Faba-beans can be utilized for pig fodder without any pre-treatment than grinding, but this knowledge need to be disseminated. Mobile grinders for pig fodder, and toasters for cattle feed, can e.g. be rented or shared, and the possibility for this could be disseminated more among farmers. Jensen et. al., (2010:206) call the low know-how of faba-bean cultivation etc. for 'a large knowledge gab'.

Farm networks play a pivotal role in achieving the above, and to sustain a further development of the Danish faba-bean 'niche', network activities by these stakeholders must be strengthened. Strengthening of the farm networks is hence needed where farmers disseminate knowledge about legumes, provide good pilot cases through farm visits, share machinery and storage capacity, and bay/sell faba-beans among each other, facilitated by means of electronic platforms and increased communication in general, etc. Such pressure on the 'regime' from the 'niche' is constituted by the organic faba-bean farmers today, but must be strengthened in the future. This 'incubation center' (Gells, 2002), composed by the 'niche', should ideally be supported by farmer organization, but this is however difficult as these organizations have an embedded reluctance to change the current 'regime'.

It is pivotal that ***farmer organization*** continue and expand its existing - albeit limited - work on legumes, as this shape and impact the entire 'regime' of Danish agriculture. Farmer organization is the Champion most reluctant to change, as they constitute the agricultural sector, strongly impacted by traditions and culture, and provide the direction for it. Changes will most likely come about slowly and require a paradigm shift from the 'landscape' level, by changes in the university curriculum of new researchers and staff connected to the agricultural sector - hereunder ***farm advisors*** - as well as farm-schools. This should be applied in combination with higher environmental awareness in the society as a whole.

Both ***seed producers*** and the ***feed industry*** are important Champions for a transition toward more legume cultivation in Denmark, and do not - like within other parts of Europe - grant legume high interest in the agro-industrial supply chain (Magrini et. al., 2016). Both stakeholders must continue their present work on developing and refining faba-bean cultivars appropriate for the Danish context, as well as providing a platform for buying and selling faba-beans. The need for better cultivars provided by these stakeholders is also stresses by Magrini et. al. (2016), and could provide higher added value and increase the interest in legumes. These Champions could be more flexible to a changing 'regime' as they most likely would like to sustain market shares in the future. If protein trade among farmers in Denmark intensifies, which could be facilitated by the farm networks, as mentioned above, changes in the existing 'socio-technical system' could appear relatively fast. As of now farmers selling/buying faba-beans among each other achieve economic benefits, compared to selling/purchase from fodder industry, as prices of e.g. wet and dirty beans are sold between local farmers at more favorable prices (higher than the feed industry pays). If protein trade among farmers intensifies, and the arable land being cultivated with faba-beans increase, seed companies could see an advantage and might be more interested to participate in order to gain and sustain market shares.

Stronger farm networks might also directly put pressure on the 'regime', as far as developing new and more suitable faba-bean seeds appropriate for the Danish context, instead of Danish farmers joining forces and purchasing seeds from abroad. As for farmer organization, both seed and fodder industries, could benefit from new learning curriculum at the 'landscape' level that might facilitate changes in the 'regime', as embedded traditions and cultures that are difficult to change would be untightened. New consumer requirements at the 'landscape' level, of e.g. more organic protein fodder being used for livestock in Denmark, could also increase the price of soy-beans, which again would make it more economically favorable to cultivate faba-beans.

When it comes to ***agricultural and environmental policy*** it would benefit the balance of Danish agriculture if the 'harmony rule' was re-introduced in Denmark. This could potentially lead to farms becoming more balanced in the size of land and number of animals (e.g. as bio-dynamic farming), as before the intensive monoculture monopolized the agricultural 'regime', where mixed farming systems were more widespread (Magrini et. al., 2016). Better frameworks for self-sufficiency, or at least increases in faba-bean cultivation, could be the result of this. Tighter environmental regulatory frameworks, supporting the growing of legumes for N-fixation and increase in the growing of domestic fodder proteins, could also be exercised. Such pressure from the 'landscape', should be adapted in Danish agriculture, as agricultural and environmental policies that promotes legumes.

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4. Conclusion

The extensive use of soy-beans for fodder proteins in European and Danish agriculture pose a serious environmental threat due to land-use changes and environmental degradation in South America countries, where a large part of the soy-beans utilized in a Danish context are being cultivated. An agriculture consisting of monoculture, primarily based on wheat, are dominating in Denmark, and massive utilization of 'external' resources like artificial N, pest and weed chemicals, fossil fuels usage, etc. are constantly fed into the system to sustain it. To increase the production of fodder proteins in Denmark, and to benefit from the many Eco System Services that legumes provide to society, this paper investigates how this can be achieves.

To enhance the faba-bean cultivation and utilization in Denmark it is important to support the activities within and create stronger farm networks at the *'niche'* level. A Transition Pathway identified in this paper is therefore activities provided by the farm networks themselves, and these networks hereby constitute a potential role as Champion. Farm networks should increase in numbers and strengths and disseminate knowledge about faba-beans cultivation and utilization as fodder etc., and intensify the sharing of farm equipment, storage facilities and increase the trade of protein fodder among farmers. These 'niche' activities could potentially intensify the pressure on the 'regime', and hence the uptake of faba-beans in the existing 'socio-technical system'. Besides this, pressure from the *'landscape'* - by changes in the learning curriculum of researchers and staff connected to farmer organizations and farm advisors, of seed and fodder companies, as well as of farm-schools, should be adopted. Compared to fodder and seed industries, which have a build in flexibility as far as creating and sustaining market shares, farmer organizations are regarded as the Champion being most reluctant to adapt to changes, and thus with the highest interest in sustaining the existing '*regime*'.

Pressure from the *'landscape'* level could also be supported by consumer groups requiring more sustainable and organic fodder for Danish livestock, and by stronger framework conditions from agricultural policies, where higher 'harmony' between farm land and number of animals are required in the future and provide an opportunity for higher level of self-sufficiency in protein fodder. Lower amounts of N-fertilizer applied on the soil, through stronger environmental policies, could also enhance farmer's cultivation of legumes in order to fix nitrogen, and benefit from the many other ESSs advantages. Hence, activities will have to be taking by various stakeholders connected to Danish agriculture at all levels of the MLP, just as policy makers and consumers etc. at the *'landscape'* level must provide a pressure and create a platform for the transition to emerge.

Acknowledgement

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Circular Design for Value-added Remanufactured End-of-Life composite material via additive manufacturing technology

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Abstract

In a context in which sustainability is going to assume an ever greater role in manufacturing and product development, recycling and reusing end-of-life materials appear as some of the major challenges in technology fields. Currently, a fair amount of methods and processes has been already developed, in order to give a second life to most of conventional materials, such as metals or thermoplastic polymers. Despite the increasing in glass fibre reinforced polymer composites structural applications (i.e. automotive, energy, constructions), it seems that their recycling and reusing are almost unexplored fields, due to the intrinsic multi-material nature. In fact, opposite to thermoplastic polymers, glass fibre reinforced composite materials are commonly composed of a thermoset matrix which cannot be melted and re-shaped after curing.

How could composites be recycled, in a circular economy model? Is there a way for their remanufacturing, so as to obtain value-added and long-lasting products? Situated within "FiberEUse" European Project, the research's main aim is to extend the life cycle of glass fibre reinforced polymer composites by using 3D Printing technology. Thus, it allows to produce environmentally sustainable objects with good mechanical properties and complex shapes, potentially suitable for a large range of application fields.

At this purpose, a low-cost Liquid Deposition Modelling technology was used, allowing glass fibre mechanical recycling for Additive Re-manufacturing. More in details, end-of-life shredded composites were adopted as reinforcement of a photo- and thermo-curable material with an acrylate-base resin as matrix: the output can be properly 3d printed by extruding the liquid material before its in situ polymerisation.

Primarily, the experimental work focused on two main aspects: the material characterization, with a remanufacturing process optimisation approach, and its application field analysis, for designing new value-added products. Regarding the first case, it was possible to better understand the way for obtaining the appropriate material composition and process settings, in order to achieve a satisfactory 3d printed outcome, as well as to unveil its mechanical and physical properties. Considering the second one, applications that could take advantages both from composites materials and additive manufacturing technology were investigated.

Through samples design and, consequently, 3d printing realisation, the whole process has been validated: new way to reuse an end-of-life composite material was given by using Liquid Deposition Modelling, promoting the implementation of a circular economy. After process parameters setting, it was possible to perform self-standing 3d prints by modulating the polymerisation directly hardening the reinforced resin after the extrusion, overcoming the current concept of supports in additive manufacturing processes.

Taking into account both the application field and the above-mentioned results, urban design could benefit

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from end-of-life composites 3d printing, giving new senso-aesthetic possibilities to designer figures. Considering both material properties and remanufacturing process, street furniture and amusement park structures will be realised directly in situ by a targeted and customised project, as soon as a future process scale-up can be managed.

Keywords: Recycling, Composite Materials, Circular Economy, Additive Re-Manufacturing, 3D Printing

1. Introduction

Currently, sustainability's importance has been strongly increased in last years, especially considering the extensive exploitation of fossil derivatives for human activity and, particularly, for the production of polymer materials (Wackernagel and Rees, 1996; Sikdar, 2003).

As a matter of fact, sustainability assumed a huge role also in manufacturing, considering not only products development and production, but also the disposal at their end-of-life. In fact, a fair amount of methods for end- of-life material recycle has been already developed, considering the most commonly used materials. On the contrary, the recyclability of fibre reinforced polymers seems dramatically poor in comparison with thermoplastics, despite their increasing spreading. In fact, the main issue is linked to their inherent multi-material nature: for this reason, composite wastes have not got experienced recycling processes, yet (Yang et al., 2012).

As regards composite materials, more than one million of tons of composite waste were produced in 2015 within the European Union. Moreover, a huge amount of composite products is reaching their end-of-life, usually from 10 to 30 years depending on their product category, i.e. recreational boats and wind turbine blades (AVK, 2017).

Accordingly, composites recover, recycle and reuse need to be further investigated, moving toward a circular economy model (Pickering, 2006; Yang et al., 2012). In order to enhance this change, material should be recovered by the reuse, recycling, repairing and remanufacturing for reducing waste and avoiding materials downcycling (Oliveux et al., 2015). At this purpose, new composites recycling methods have been developed paying close attention to high-quality recovering, although intrinsic material problems: mainly, scale-up problems are linked to equipment costs and energy demands, outweighing the economic benefit. In a circular economy approach, these issues should be overcome (Mativenga et al., 2017).

Inevitably, the scale-up trouble is also referred to glass fibre reinforced composites (GFRCs) due to their increasing fields of application. Investments can indeed overcome the intrinsic value of recovered products, avoiding real recycling technologies adoption, in contrast to carbon fibres recycle (Wang et al., 2018).

Although the Europe GFRCs production volume is at least one order of magnitude higher than carbon fibre reinforced polymers (CFRPs), GFRCs recycling and reusing seems almost unexplored, especially comparing thermoset matrix behaviour to thermoplastics (AVK, 2017). Actually, their recycle is possible adopting mechanical grinding and pyrolysis, while the reuse for new products can be made by splitting, hot and cold crushing and hot forming (Åkesson et al., 2012; Adams et al., 2015). In industrial application field, GFRCs recycle can be achieved by mechanical recycling, obtaining different qualities and dimension of recyclates, in order to use them in different applications and with several production techniques (Beauson et al., 2014; Shuaib & Mativenga, 2016).

With regard to other technologies, additive manufacturing (or 3D printing) has been emerging as a good solution for composite material use, manufacturing new products through a layer-by-layer material addition (Wang et al., 2017). Thanks to its several advantages (i.e. shape complexity and freedom, customization, cost reduction in product development and scraps reducing), 3D printing seems to fit well with composites recycling, in order to produce filament or 3D printable inks for low cost 3D printers (Ostuzzi et al., 2015; Griffini et al., 2016; Cruz Sanchez et al., 2017; Mohan et al., 2017; Tian et al., 2017; Mantelli et al., 2019).

Similarly, additive manufacturing could enhance circular economy model diffusion, generating new value in 3D printed products (Despeisse et al., 2017). At the same time, design methods allow to put these models into practice (Moreno et al., 2016) and new related application fields have been developing in last years (Rayna and Striukova, 2016; Ngo et al., 2018).

For all the above reasons, a new way for GFRCs re-manufacturing via 3D printing for new design applications should be the missing gap in circular design approach real application: in this regard, the present research's principal aim is to link these elements in a single process.

In this work, an additive re-manufacturing process for GFRCs recycle was presented and redefined, in order to reuse shredded solid recyclates GFRCs. Through an UV-assisted 3D printing process, a 3D printable material (or ink) made by an acrylic-based photo- and thermo-curable resin and wind blade turbines glass fibres thermoset composites was first developed. Then, the material was optimized in terms of different component percentages, printability of the extruded inks, UV conversion of printed cured materials, rheological properties and mechanical behaviour.

Later, surface finishing and senso-aesthetic properties were examined and, at the end, new environmentally sustainable objects for urban design applications were presented, in order to make them real thanks to a future process scale-up.

2. Methods

3D Printable materials were mainly composed by a photo- and thermo-curable acrylic-base resin matrix and recycled GFRCs powder reinforcement (or recyclate GFRCs), mixed in different percentages.
In its turn, the acrylic-base matrix consisted of the ethoxylate bisphenol A diacrylate resin (hereinafter named SE349, purchased from Arkema and locally distributed by Came S.r.l., Italy). Other components in different percentages were added to the matrix as polymerization and filler addition enhancements:

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Butanediol dimethacrylate as filler percentage enhancer (BDDMA, purchased from Sigma-Aldrich, Italy), Dicumyl peroxide as thermal activator (purchased from Sigma-Aldrich, Italy) and Ethyl phenyl(2,4,6-trimethylbenzoyl) phosphinate as photo activator (hereinafter named TPO-L, purchased from Lambson Limited, UK).

SR349 and BDDMA percentages were investigated during the experimentation, while TPO-L and Dicumyl peroxide were added using fixed proportions (3% wt. of TPO-L and 0,3% wt. of dicumyl peroxide) investigated by previous works (Mantelli et al., 2019).

Recycled GFRCs derived from Siemens Gamesa Renewable Energy S.A. end-of-life wind turbines. In order to be suitable for additive remanufacturing, turbine's scrap GFRCs had to be shredded up to become fine powder. For the following experimentation, Recycled GFRCs powder was shredded and supplied from Centro Nazionale di Ricerca (CNR), Italy.

By thermogravimetric analysis (TGA) and, consequently, its curves evaluation, it was possible to define the glass content of the recycled powder, here shown in Table 1. Each raw material was used as received.

Table 1. *Glass Fibre content (estimated by thermogravimetric analysis), mean fibre length(l), mean fibre diameter (d) and geometry factor (□) for recycled GFRC powder (estimated by scanning electron microscopy analysis).*

	Glass Fibre Content (% wt.)	Fibre length, l (μm)	Fibre diameter, d (μm)	Geometry factor, □ (2*l/d)
Recycled GFRC powder	70±1	34.4±47.7	13.5±6.0	4.6

Formulations were obtained by mixing the matrix components in the established percentages with a magnetic stirrer at room temperature for 2 hours. Afterwards, Recycled GFRCs powders were incorporated to the resin system: initially, they were manually inserted and mixed (for less than a minute), in order to include the volatile powders into the matrix. For obtaining a homogeneous and printable material with a good repeatability, the material needs to be successively mixed by using a mechanical stirrer equipped with a shear stress impeller for 2h at 250 rpm or with a Brabender mixer (C.W. Brabender Instruments, Inc, US) equipped with a roller blade for 45 minutes at 40 rpm. Through this process, it was possible to add a major percentage of recycled GFRCs powder into the acrylic based matrix as presented by previous works (Mantelli et al., 2019). Figure 1 shows the formulations obtained and here studied either with the Brabender mixer or the mechanical stirrer, made by increasing weight concentrations of recycled GFRCs powders and varying BDDMA percentages: for short, the 3D printable material formulations will be referred to as XDYR (where X is the BDDMA reactive diluent concentration and Y the recycled GFRCs percentage).

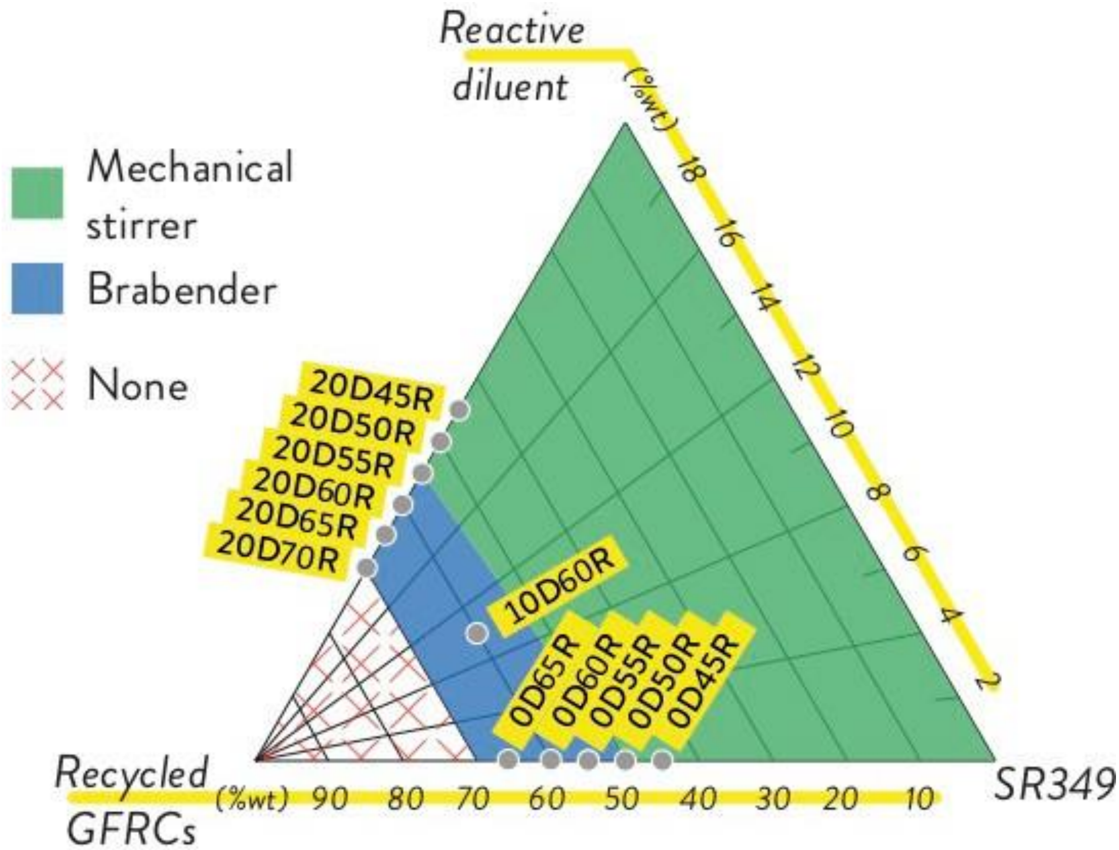

***Figure 1**. Composition graph: the analysed 3D printable ink formulations are highlighted in yellow. The green and blue areas respectively indicate the compositions mixed with a mechanical stirrer or a Brabender mixer. Finally, the red crosses area indicates material formulations with inadequate processability.*

For 3D printing tests, a 3Drag FDM 3D printer (supplied by Futura Group Srl, Italy) was modified as in previous works (Griffini et al., 2016; Mantelli et al., 2019), becoming a Liquid Deposition Modelling (for brevity, LDM) 3D printer, suitable to deposit low viscosity liquids layer-by-layer from a non-heated nozzle linked to a syringe extruder, moved by an endless screw system. The 3d printer was also equipped with three LEDs with a light emission peaked at 395 nm, controlled by a dimmable driver LED DI0001LE, supplied by Tecno Switch, Italy, in order to start material's in situ polymerization.

Considering 3D printer modification, custom pieces were designed by using "Fusion 360" CAD software (Autodesk, US) and "Slic3r PE 1.41.3" open source slicing software (Prusa Research, Czech Republic) and 3D printed with Prusa i3 MK3 FDM 3D Printers (Prusa Research, Czech Republic).

Primarily, LDM 3D printer was used for UV-3D printing samples (process parameters definition and surface finishing test), material and mechanical characterization specimens, and design application scale model. In this case, samples and product concept 3d models were designed using "Solidworks" CAD software (Dassault Systèmes, France) and sliced for LDM process with "Cura" open source slicing software (Ultimaker B. V., Holland).

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Regarding 3D printing fixed parameters, print speed ranged between 5 and 10 mm/s and layer height changed between 0,25 and 1 mm, using a stainless steel conic nozzle with a diameter of 1.04 mm.

3D Printable material physical and mechanical characterization was made by combining different kind of test (TGA, rheological tests, photo-DSC, tensile test), giving a feedback both for 3d printability and design applications. Considering the material, each kind of test was performed at a different step.

First, TGA was performed on recycled GFRCs powders with TA INSTRUMENTS Q500 TGA (TA Instruments, Inc, US), heating the samples from 25°C to 800°C with a 25°C/min heating rate under an air environment.

Meanwhile, SEM images were realized with Cambridge Stereoscan 360 (Cambridge Instrument Company Ltd, UK). Moreover, all the SEM images were obtained using a secondary electron probe and sample surfaces for the analysis were previously prepared with a physical vapour deposition of gold for 1 minute.

Then, rheological tests were performed on non-polymerized 3d printable material with Kinexus DSR (Malvern Panalytical Ltd., Uk): before the measurements, a constant shear stress was firstly applied for 1 minute (10 Pa for samples with 30% and 45% wt. of recycled GFRCs powders, 1000 Pa for samples with 50, 55, 60 and 65 % wt. of recycled GFRCs powders), followed by 3 minutes' rest period. Moreover, tests were carried out with a 20 mm plate-plate geometry and a 0,7 mm gap and a stress ramp test was performed from 10 Pa to 20000 Pa in 20 minutes, after the rest period (when 1000 Pa pre-shear was applied, the stress ramp measurement started from 100 Pa).

Reactivity measurements were made by Photo-DSC analyses using UV-3d printed samples with a Mettler-Toledo DSC/823e (Mettler Toledo, US), equipped with Lightningcure LC8, Hamamatsu Photonics, Japan. Mainly, tests were performed exposing the samples for 3 minutes to a 365 nm UV radiation (607.7 mW/cm2) twice and the difference in enthalpy between first and second runs was used to measure UV conversion. For performing DSC tests in N2 environment, heating/cooling ramps from 25°C to 250°C with a 20°/min heating rate were used: so, the exothermic heat flow caused by unreacted groups polymerization was measured in the first ramp, while material glass transition temperature was evaluated in the second one.

In order to perform tensile mechanical properties, UV-3D printed samples had to go through photo and thermal treatment, avoiding partially polymerized areas. Therefore, UV post-curing treatment was performed using a UV chamber Polymer 500W (Helios Italquartz S.r.l., Italy) equipped with a UVA emittance mercury vapour lamp type Zs (950 W/m2) for 15 minutes each side, while thermal post-curing one was carried out by simply heating samples in an oven for 2 hours at 140°C.

Through a Zwick Roell Z010 (ZwickRoell GmbH & Co. KG, Germany) equipped with a 10 kN cell load, tensile mechanical properties were obtained, following the ASTM standard test method D638 – 14 (2014) and D3039/D3039M-17(2017). In the experimentation, specimens had a gauge length of 40 mm, a width of 10 mm, an overall length of 100 mm and a thickness of 2 mm and test speed was 5 mm/min. Moreover, material formulations used for tests was 0D55R and, before tensile tests, specimens were manually polished, in order to eliminate 3D printing typical roughness.

At the end, elastic modulus was predicted by using the Halpin-Tsai model and compared with experimental results.

3. Results and Discussion

3.1. Printability

Through fine process parameters variation, it is possible to 3d print photo- and thermal-curable 3d printable materials (or inks) with different percentage of recycled GFRCs powder and, consequently, various viscosities.

Substantially, printability tests consisted in finding the optimal parameters for 3D printing different material formulations: the main change in each composition is the recycled GFRCs quantity mixed with the matrix, affecting material extrusion's aptitude.

Very first tests were made by 3d printing tensile test 3d model, with a 100% infill and 0,25, 0,5 and 1 mm layer height, starting from a 20D55R formulation. At the beginning, reactive diluent concentration was fixed according to previous works (Mantelli et al., 2019), while recycled GFRCs powder quantity was incremented during mixing step. In fact, material behaviour appeared inappropriate for LDM: during the extrusion trials, the formulation flowed in an uncontrolled way, depositing too much material and causing both lateral spreading and geometry inaccuracies.

Regarding 3d printing quality, efficiency and extrusion ease, some printability issues were also linked to the previous LDM 3D printing system used: at this purpose, a new extruder system has been redesigned, focusing on a new stiffer structure. In addition, syringe (with capability fro 10 ml to maximum 60 ml) is better fixed to the extrusion system, avoiding syringe plunger's torsion during the process and improving flow stability. UV Led support system was not subject to significant variations from the previous version, that already reached a homogeneous distribution of the UV radiation on the 3D printed piece. In Figure 2, the new LDM extruder system scheme is briefly represented.

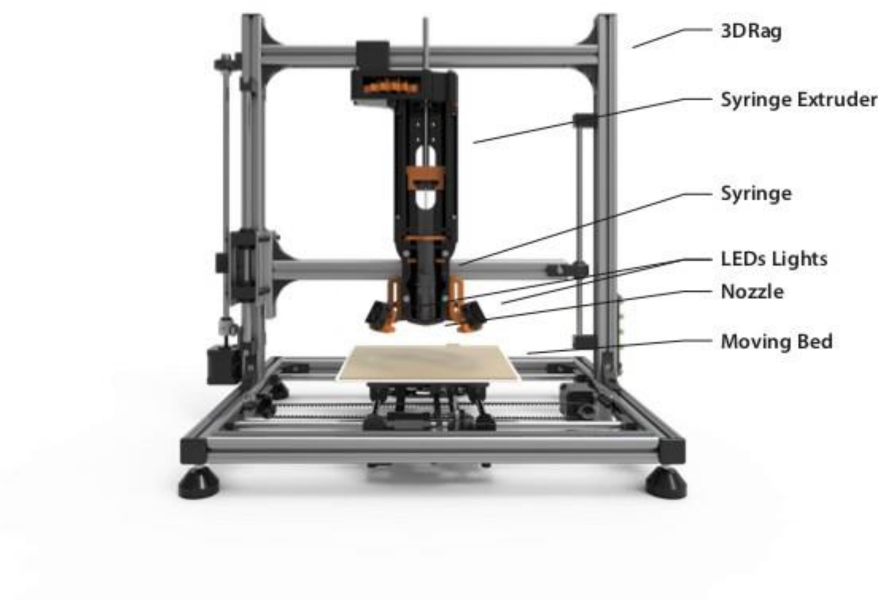

***Figure 2**. Representation of the UV 3D printing modified in this work.*

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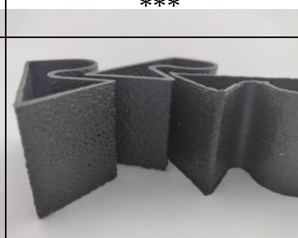
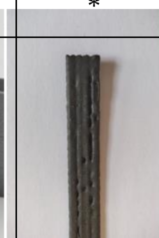
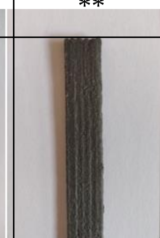
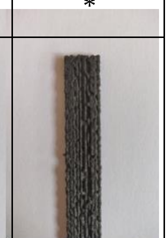
After the 3D printing upgrade, tests on printability started again with the 20D55R formulation and, in order to set the stepper motor motion on the endless screw (measured in rpm): this operation allows to control the extruded material quantity, matching the GCode extrusion length to the one performed by the machine. In fact, to 1 mm extrusion set in the GCode should correspond 1 mm real extrusion made by the 3D Printing. By increasing the recycled GFRCs powder amount, the material printability was strongly decreasing, even if the percentage was just slightly augmented: theoretical maximum content of recycled GFRCs is 60% vol., that corresponds to 70% wt. (). Furthermore, BDDMA reactive diluent addition was investigated at different percentages (0, 10 and 20% wt.) and, considering the same amount of recycled GFRCs, avoiding its use improved 3D printing quality, despite of previous work. In fact, formulations with reactive diluent trend was to be easily extruded at the beginning, leaving a material with a higher GFRCs concentration in the syringe, as if the matrix was divided from the filler.
According to Table 2, the best 3D printable material was 0D55R formulation, that grants a good flow and less nozzle obstruction if compared to the other compositions.

Table 2. *Printability tests with different material formulations and printing parameters, i.e. flow percentage, speed and layer height: (a) 20D55R tensile test specimen, (b) 0D55R finishing samples, (c) 20D60R tensile test specimen, (d), 0D60R tensile test specimen, (e) 20D65R tensile specimen.*

Sample	20D55R	0D55R	20D60R	0D60R	20D65R
Flow (%)	90	100	120	105	140
Speed (mm/s)	10	9	7	5	5
Layer Height (mm)	0.25 - 1	0.25 – 0.75	0.5	0.5	0.5
Printability	**	***	*	**	*
	 (a)	 (b)	 (c)	 (d)	 (e)

In addition, other process parameters were modified, in order to improve layer adhesion, reduce material voids and nozzle obstruction during 3d printing: LED intensity was from 50% to 70% decreased thanks to the dimmable driver, giving more time to the extruded material for depositing and adapting on the previous layer before its in situ polymerization. Hereafter, this operation will be called “under-polymerization” and its intensity will be modified between according to 3D model geometry and infill/shell parameters.

Due to bottom layer importance for FDM and LDM processes, matching the under-polymerization with a fine z axis calibration contributed to 3D printing quality improvement, achieving good results using spiral slicing option, single and double wall thickness and infill presence.

Contrary to Griffini and coworkers study (Griffini et al., 2016), material photo-polymerization was not affected by recycled GFRCs presence: in fact, all the formulation had a dark grey colour appearance, that could reduce photopolymerization efficiency. However, this unexpected behaviour could be deeply studied in next works.

3.2. Material Characterization

The recycled material was first studied: the glass fibre content, evaluated from TGA measurement, is equal to 70±1%wt. More specifically, the result confirms the high content of glass fibres expected in a composite part and also the conservation of the material constituent during the shredding process. Then, the recycled powder was studied with SEM micrograph: a representative image is visible in Figure 3. The glass fibres were measured from the images and the result will be used later for the young's modulus prediction with Halpin-Tsai model.

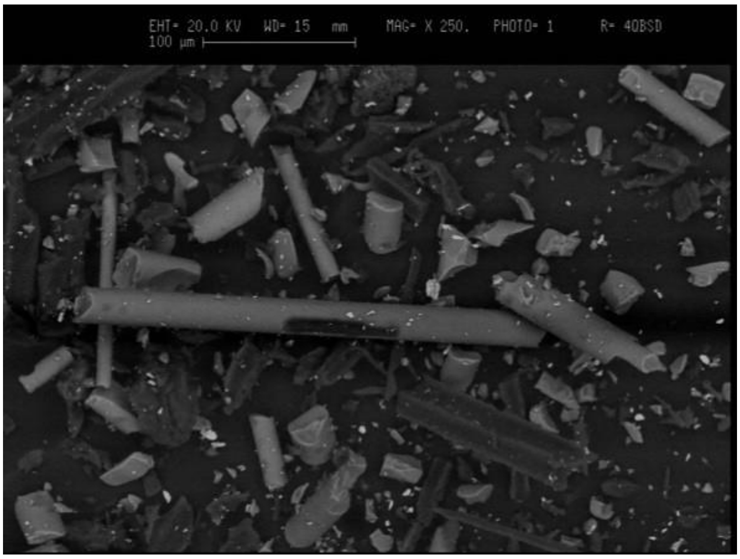


***Figure 3**. SEM micrograph of the recycled GFRC showing the presence of different glass fibres with different diameters.*

The 3D printable ink rheology test visible in Figure 4 shows that the material has a pseudoplastic behaviour. The effect of the increased content of recyclate higher the pseudoplasticity behaviour, moreover the introduction of a reactive diluent lowers the overall viscosity. From the graph, it is clear that a 5% wt. increase in recycled GFRCs content produce an increase of the apparent viscosity of one order of magnitude. Furthermore, the addition of 20% reactive diluent to the 55% wt. recyclate formulation produce a decrease of one order of magnitude to the apparent viscosity. As a consequence, considering that the best performing 3D printable material has an apparent viscosity of 200 Pa·s, higher viscosity materials produce higher resistance to flow and more difficulties in the extrusion process. On the contrary, lower viscosity inks are difficult to be extruded in a controlled manner. As an open point, the separation of the resin system and

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recycled GFRCs powder, particularly for the inks containing the reactive diluent, has to be further studied.

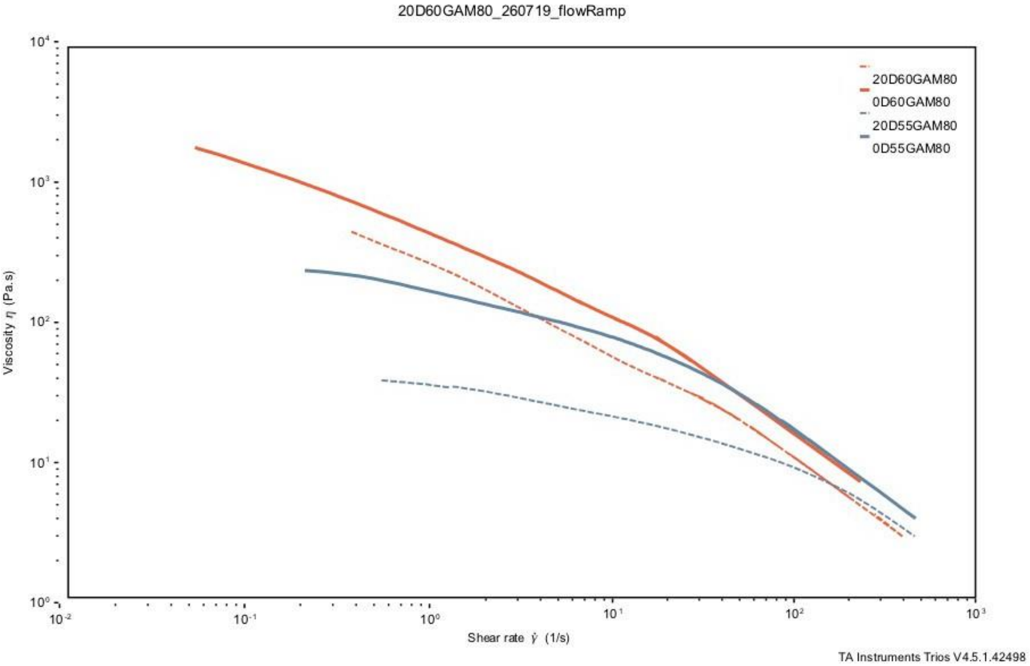

Figure 4. *Stress ramp test results for 3D printable materials containing 55 and 60% wt. recyclate both without reactive diluent and in its presence.*

Primarily, the UV reactivity of the material was studied in order to understand if the concentration of recycled GFRC has an influence on its reactivity. The UV-conversion related to UV exposure was determined by measuring the exothermic enthalpy produced during UV-crosslinking for the neat resin and for the 3D printable ink as follows:

$$UV_{conv.} = \frac{\Delta H_{sample}}{\Delta H_{neat\ resin}} \times 100 \quad (1)$$

As can be seen in Figure 5a, the 3D printable material has a quite high UV-conversion even at higher concentrations. As a consequence of the high UV-reactivity during the 3D printing process, the 3D printable material can easily clog the nozzle. To overcome this problem, the UV-LED power was reduced by at least 50%. Controlling the crosslinking kinetics of the 3D printable material flowing out of the nozzle, it was possible to obtain a good shape retention without clogging the nozzle. As discussed in the previous chapter, the UV power control has a consequence also on printability and 3D printed sample quality.

After 3D printing, the UV-DSC test was repeated and the residual conversion (residual enthalpy of 3D printed samples) of a 3D printed sample visible in Figure 5a is very low. Therefore, this result confirms that even in under-polymerization conditions the UV-conversion during the 3D printing process is higher than the 60%, which is a sufficient value for shape retention.

In order to complete the UV-conversion, a UV-post curing cycle is applied to the 3D printed sample.

According to Figure 5b, an exothermic enthalpy is clearly visible after the UV-post curing, which is no more visible after the thermal post curing treatment. Thus, it is confirmed the thermal post curing cycle need, defined in the previous work (Mantelli et al., 2019). After the whole post curing treatment, it is possible to see that the material has a relatively high glass transition temperature at 100°C.

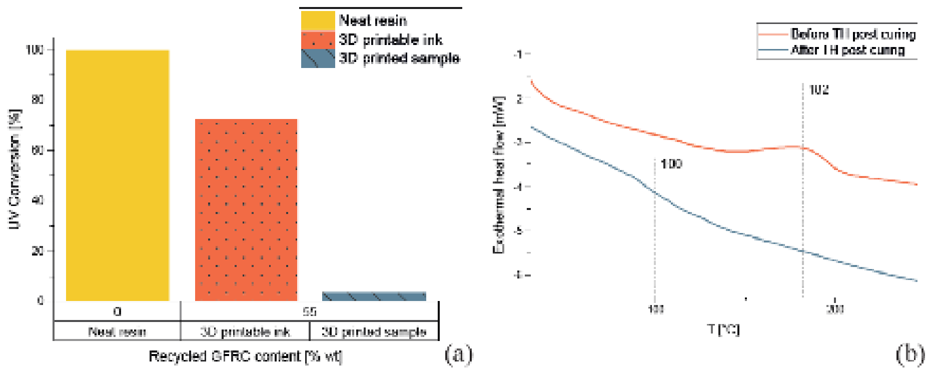

Figure 5. *DSC analyses for 3D printable material before and after 3D printing (with different recycled GFRCs percentages): (a) UV conversion of 3D printable materials evaluated by PHOTO-DSC, (b) DSC first heating ramp showing the exothermic peaks' presence for 3D printed samples after a UV post-curing treatment and third heating ramp showing where the glass transition temperature is present.*

Taking into account the previous DSC analysis results, the workflow that starts from the 3D printable material mixing to the final object is summarized as follows in the Figure 6. Even though the 3D printed object has already a fixed and manipulable shape due to the UV-assisted process, the UV post curing and the thermal one have a big role in order to complete the material crosslinking.

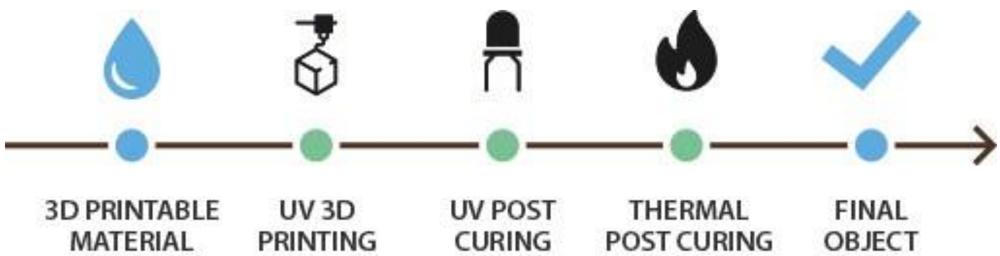

Figure 6. *UV 3D printing main steps: 3D printable material mixing, UV 3D printing (obtaining the 3D printed object), UV post curing (UVA 950 W/m² for 30 min), Thermal post curing (140°C for 2 h, obtaining the final product).*

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Then, the mechanical behaviour of the 3D printed material was studied accordingly to the standards for composites material. Particularly, the results are compared to the neat resin mechanical properties and with the predicted young's modulus calculated with Halpin-Tsai model for aligned fibres (Halpin and Kardos, 1976).

As can be seen from Figure 7, the measured elastic modulus is comparable with the predicted one, confirming the fibres alignment during deposition. Moreover, the two-fold increase in elastic modulus compared to the neat resin is a good result, especially considering the relatively low amount of glass fibres present in the formulation. For the mechanical properties at failure, the results are for a practical point of view similar to the neat resin one.

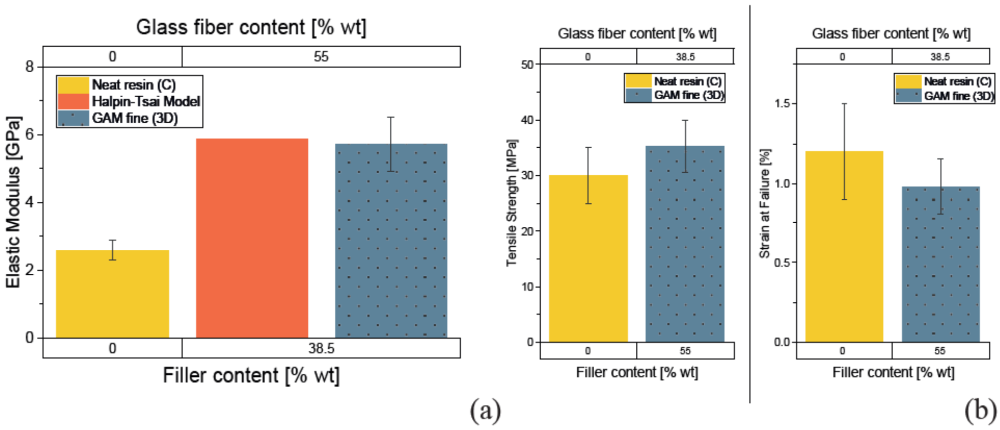

Figure 7. *Tensile test results: (a) experimental value of elastic modulus with theoretical values (Halpin-Tsai model), (b) experimental values of ultimate tensile strength, and (c experimental values of strain at failure.*

3.3. Surface Finishing and Senso-aesthetic Features

According to printability tests, surface finishing related to 3d printing re-manufacturing parameters and senso- aesthetic features were investigated.

In literature, material surface finishing importance is well-known, not only for material science, but also in design fields: senso-aesthetic (sensual, aesthetic, and psychological) properties are strictly related to human perception (Hartcher-O'Brien et al., 2019) and, in turn, they are strongly affected by physical and chemical material properties. Furthermore, both vision and touch have a big role in material texture perception (Whitaker et al., 2008).

In addition, manufacturing methods have a big role in surface definition, both considering limits (i.e. roughness, tolerances) and possibilities (i.e. texture definition).

Despite senso-aesthetic properties are subjective and perception could change from an individual to another, previous works have already defined some guidelines (Zuo et al., 2001; Zuo and Jones, 2005). Moreover, material libraries have been assuming an ever great role in design process and product definition, giving physically access to materials samples with different properties and surface finishing (Miodownik, 2007).

After defining the best 3D printable material, senso-aesthetic properties were explored together with process parameters by means of 3D printed samples. In particular, 3D model was expressly designed for LDM process features, considering a medium shape complexity, low building times and process parameters variation ease (overall dimensions: 25x50x30 mm).

Therefore, it was possible to obtain a little surface finishing selection of the 3D printable material made by nine 3D printed and finished samples. As shown in Figure 8, specimens were organized in three main groups: layer height variation (0,25, 0,5, 0,75 mm), printing mode (spiral, two shells, two shells with infill) and post processing finishing (after LDM process, polishing and gel coating, polishing with painting and gel coating). For samples realization, 0D55R material formulation was adopted.

In general, LED settings were adopted accordingly to Printability paragraph and reduced to 70% by the dimmable driver: this permitted to the 3D printable material a better deposition during the extrusion, increasing surface quality. Moreover, decreasing print speed (according to layer height or printing mode) improved 3d printing overall quality, avoiding failures.

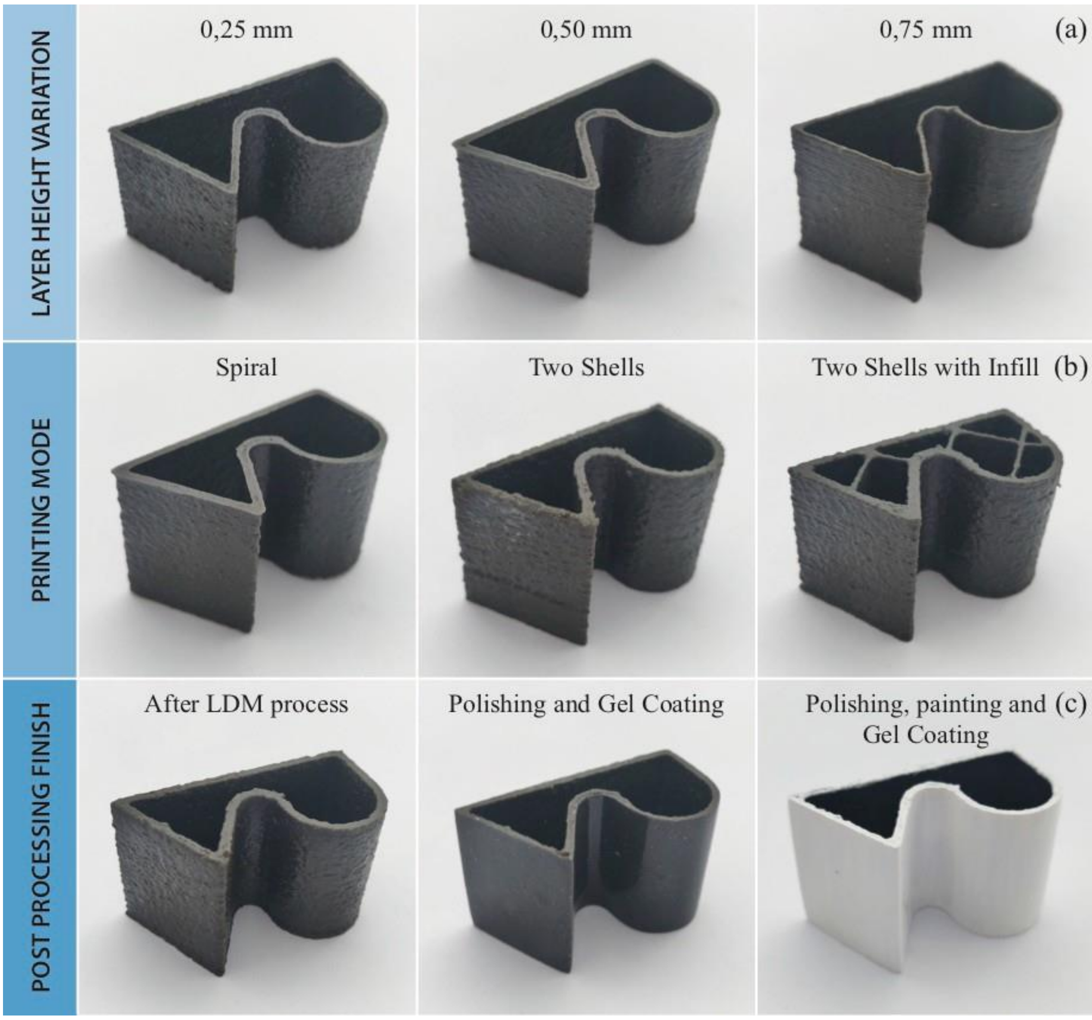

***Figure 8**. Surface Finishing Selection of 3D printable material (0R55D) divided in (a) Layer Height Variation,*

(b) Printing Mode and (c) Post Processing Finishing.

Considering layer height variation (Figure 8a), 3D printing layer-by-layer surface finishing is more noticeable in 0,75 mm sample: in the other ones, layer-by-layer effect is strongly reduced by the flow deposition.

Despite LDM layers are thicker than FDM ones thanks to greater nozzle sizes, 0,25 and 0,5 mm samples

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have not a defined layer-by-layer surface: on the contrary, layers seemed merged by a surface texture created during the extrusion. More in detail, a random pattern was generated in 3D printing phase. The pattern changed even using the same GCode file and printing settings, too.

In figure 8b, it is shown printing mode change through three 3D printed samples. Even though there is not a significant variation in surface quality, the two shells specimen seemed to have the best layer adhesion, without visible voids. Infill creation was possible, even if it required an accurate travel speed setting for flow deposition improvement.

Finally, post processing treatments on two samples were performed after photo and thermal treatment (shown in figure 8c) and compared with a non-treated one. More in detail, the two 3D printed pieces were manually polished and finished with a transparent gel coating and a white acrylic-based paint with transparent gel coating, respectively. Due to the surface treatments, overall roughness was strongly reduced, improving environmental resistance and changing material's perception.

To sum up, different layer height and printing mode were successfully investigated, changing surface quality and finishing. Although it is not possible to suddenly stop the material flow for moving the nozzle to another position without extrusion issues, LDM process could generate specially designed highquality products.

Focusing on material perception, the combination between the surface random pattern and material colour give to the 3D printed samples a raw stone-material appearance. Especially, each piece seems unique and hand-crafted, generating an extra added value due to its finishing.

Making a comparison between the actual samples and previous works one shown in Figure 9a (Mantelli et al., 2019), it is clear that layer-by-layer appearance is strongly reduced by the material formulation, which is in turn affected by recycled GFRCs powder provided in this work (Figure 9b).

Advantages due to this specific surface finishing will be discussed afterwards, linking them to design applications.

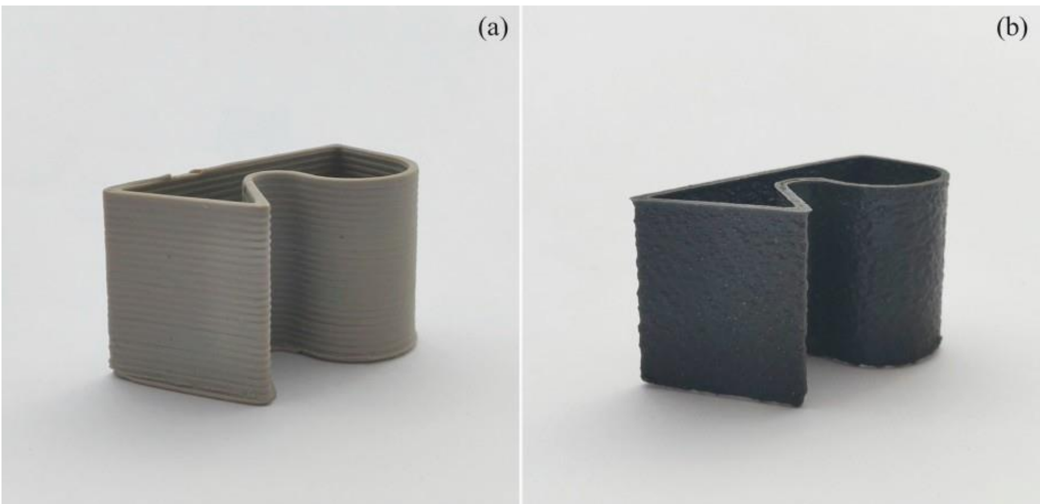

Figure 9*. Surface Finish after LDM process of different recycled GFRCs: (a) material formulation from Mantelli et al. (2019), and (b) from this work.*

3.4 Additive Re-manufacturing and Design Applications

After surface finishing exploring and senso-aesthetic definition through samples realization, design applications should be investigated, in order to exploit recycled GFRCs powders and 3D printable materials.

Thanks to their properties, new design fields could be reached, enhancing innovation. Therefore, new materials have to be implemented in materials selection, encouraging designers to taking them into account both from a technical engineering and a user-centred design point of view. Moreover, this effort should be done from the early design phases, impacting on life cycle costs (Veelaert et al., 2016).

With respect to a circular economy approach, additive manufacturing materials have been used for reducing products environmental impact by taking advantage of on-demand and in-situ production, reducing transportation costs. At this purpose, several applications could be found in architecture and building field: due to overall product dimensions, manufacturing could be significantly supported. Furthermore, recycled materials have the possibility to generate new value through 3d printing, generating high added-value applications especially from large-scale mass customization (Rayna and Striukova, 2016; Ngo et al., 2018).

Despite full-scale construction via additive manufacturing is still in an emerging phase, construction field and urban design could beneficiate from 3D printing adopting. In fact, material is used in an optimized way, reducing wastes, avoiding damages caused by transportation and, generally, decreasing environmental impact from the initial construction phase to the End-of-life one (Lim et al., 2012; Dixit, 2019).

From a senso-aesthetic point of view, 3D printed samples raw stone-material appearance as investigated above combines well with outdoor construction applications, with similar surface finishing and colours, as well as less layer-by-layer look. As previously mentioned, the random texture and raw stone-material appearance can be easily attributed to buildings and outdoor application fields, reminding other materials that are widely diffused in these contexts, such as ceramic, concrete and stones.

Moreover, this non-3d printed appearance could be advantageous for post processing costs reduction, avoiding expensive treatments in order to improve surface roughness. Actually, outdoor applications will not have a layer- by-layer look, even though any polishing treatment is not performed. In this case, the limit would be due only to 3d printing quality, in its turn obtained by a fine UV and 3D printing parameters setting.

For all these reasons, outdoor architecture, urban design and scenography elements located in amusement parks are suitable for recycled GFRCs printable materials use. In fact, public and private infrastructures made by recycled end-of-life material could generate added-value and, simultaneously, reduce environmental impact. Considering End-of-life composite material annual quantities, construction-scale products seems the best method for reusing a remarkable material amount, avoiding desktop-scale 3d printing pieces.

As a consequence, street furniture, scenography elements and amusement park products made by recycled GFRCs via additive manufacturing will be manufactured directly in-situ, taking advantage both from 3D printing (i.e. customization, complex shapes and low production batches) and composite material properties

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(i.e. good mechanical properties, unique senso-aesthetics features). In addition, circular economy key elements could be achieved through the whole process, with significant value addition.

As a proof-of-concept, a scale model of an amusement park main entrance was 3D printed with the 0D55R material formulation, previously designed in other works (Paracchini, 2018): as shown in Figure 10a, a GCode from the STL file was obtained and subsequently printed by UV-assisted LDM process. More specifically, the overhanged entrance was a self-standing structure, that has a tilt angle of 30° with respect to the printing surface. In this case, it was possible to 3D print it without any support, thanks to a fine photopolymerization modulation that directly hardened the material after the extrusion (Figure 10b). After UV and thermal post curing, the 1:50 scale model was assembled (Figure 10c): surface finishing was similar to 3D printed samples here as well.

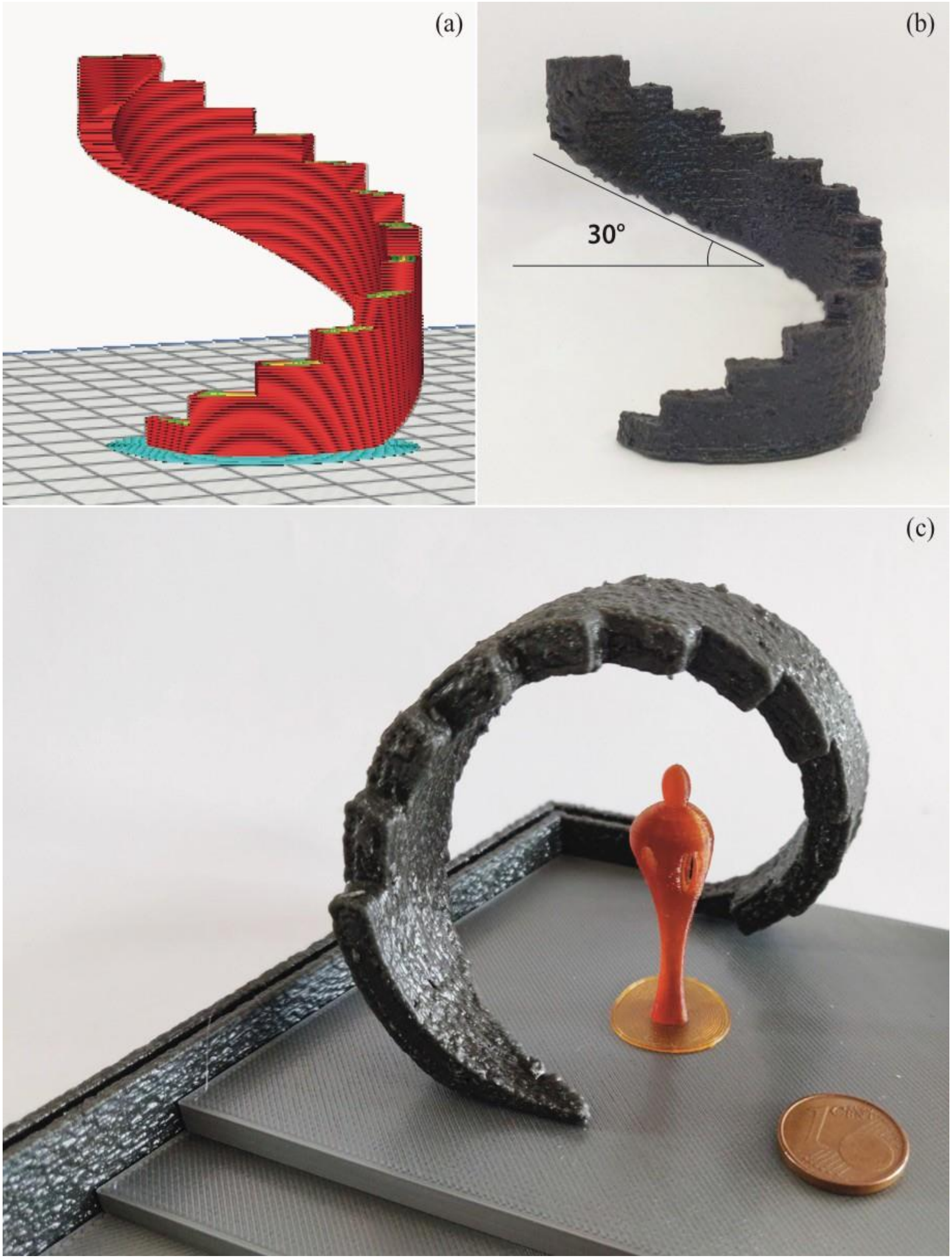

Figure 10*. Additive Re-Manufacturing: (a) G-Code preview of the 3D printed structure and (b) the corresponding 3D printed object obtained by the LDM process, (c) showed as 1:50 scale model for amusement park attractions and outdoor architecture application.*

As regards process parameters modifications, a new proof-of-concept was performed, in order to validate under- polymerization and led intensity reduction. In other words, layer adhesion improvement was tested by 3d printing a two shell box with a simple shape. After post curing, the box was filled with coloured water and potential water

leaks were checked, in order to verify layer adhesion. In brief, the sample box showed a rudimental water-

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tight, that needs to be further analysed in next works.

Accordingly, design fields could be extended to water-based applications, particularly linked with urban design and amusement park structures for decoration purposes, for instance outdoor decorative pools, water park scenography, fountains.

In Figure 11a, different fountain concepts are shown. Despite the material should be tested for allowing human water-contact without health issues, drinkable water fountains could be 3d printed by designing inner hollows for water piping insertion, validating their urban design application.

Then, a 1:20 scale drinking fountain was designed and subsequently 3D printed via UV-assisted LDM technology with the 0D55R material formulation: the overhang complex shape was achieved thanks to the under- polymerization combined with the “on-air” 3D printing mode (Figure 11b). As soon as the LDM scale-up process is tested and validated, further applications and design concept could be developed and widespread.

Figure 11. *Additive Re-Manufacturing: (a) Design concepts of water decoration structures for urban design and amusement parks (fountains), and (b) 3D printed 1:20 scale structure obtained by LDM process with 0D55R material formulation.*

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4 Conclusions

To sum up, a 3D printable material made by a photo- and thermo-curable acrylic-based thermoset matrix and recycled GFRCs powder for UV-assisted 3D printing via Liquid Deposition Modelling (LDM) was developed. As a consequence, an additive re-manufacturing process was redefined, validating UV LED under-polymerization and 3D printing parameter settings. Therefore, a UV-assisted 3D printing of 0D55R material formulation was achieved with a good overall quality.

Then, material characterization of 3D printable inks was performed, defining at first GFRCs powder main features. From 0D55R material formulation, rheological properties were analysed, showing a pseudoplastic behaviour. Moreover, UV and thermal post-curing minimized the residual unreacted groups in 3D printed pieces. Mechanical properties were also investigated, confirming the Halpin-Tsai model prediction.

As regards surface finishing and senso-aesthetic properties, a selection of nine 3D printed samples was realized, considering layer height variation, printing mode and post process finishing: process parameters allowed also to obtain an improved layer adhesion and, consequently, a non-3D printed appearance using specific settings.

In line with recent 3D printing design trends, new design application for urban design and water-contact urban design were found, thanks to scale models and structure realization. Furthermore, self-standing and water-tight structures were obtained by modulating the UV LED intensity during the 3D printing, avoiding supports.

Despite next works are necessary in order to better investigate under-polymerization effects, process scale-up and material characterization, this study leads the way to GFRCs recycling for urban design and construction fields, with unique senso-aesthetic properties for designers.

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Consumption in the circular economy: consumer behaviours and activities

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Abstract

Despite the central role consumers will play in achieving circularity, research on the effects of circularity on consumption is somewhat limited. Instead, most of the existing studies addressing the circular economy identify strategies and business models that companies should implement to become circular without considering the consequences on the demand side. By omitting the consumption perspective, circular economy design and development processes will result in offerings that consumers will not adopt. To contribute to the literature on consumption and the circular economy, and to improve the understanding of such issue, this study investigated the actions involved in the consumption process of a specific type of circular offerings. To address this aim, the study draws on the fields of service design and consumption studies, to analyse data from three case studies offering use-oriented product-service systems in the fashion sector. Based on the qualitative analysis of the data, the study found that the consumption process involving circular offerings, does not only change what happens during the acquisition or disposal moments, but it also requires actions that enable the appropriation, appreciation, devaluation and divestment of the offering. Such actions are different for the tangible or intangible aspect of the offering. Each of these moments, offers an opportunity to design and develop offerings that account for the user's experience, and if done properly, can deliver real value for the customer. Some interesting findings suggest that this type of offering may contribute to inequal access to clothes by favouring people that have access to digital and credit infrastructures. Data also suggest that people can derive several benefits, including symbolic, economic, and functional ones. Nevertheless, users are expected to give up sensitive information, and control. Future research can broaden the scope of data sources to populate some of the insights offered here. Moreover, it is suggested that new studies focus on how circularity influences each of the components of use-oriented PSS in different sectors.

Keywords: Circular Economy, Circular Consumption, Consumer Behaviour, Service Design

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1. Introduction

Since 2014, various businesses endorsing the circular economy have been recognised and praised for their potential contribution to a successful transition towards the circular economy in high-level economic events such as the World Economic Forum. However, a quick screening of their value propositions reveals that customers play a critical role in realising their circularity potential. Nonetheless, in the absence of the right incentives and conditions, people will not act in the expected way (Ajzen, 1991). In a linear economy, consumers are the endpoint in a company's value chain, and because of it, companies direct all their resources to get consumers to purchase their product or service. In contrast, in the circular economy, consumers are not the endpoint anymore; they become product and material stewards, changing the relationship between company and consumer.

Despite the relevance of consumers and consumption in the circular economy, most literature available analyses how production processes and business models change in this new context (European Commission, 2017; Van Eijk, 2015; Wijkman and Skånberg, 2015) and provide guidance on strategies to achieve such transformation (Linder and Williander, 2017; Moreno et al., 2016). Focusing primarily on the production side can have two consequences. On the one hand, it can reduce the intervention landscape for the companies, and on the other, it may hamper the chances of delivering real value for consumers (Kirchherr et al., 2017).

In an effort to tackle these limitations and with the aim of further contributing to improving the understanding of the circular economy from a consumption perspective, this study investigates the actions that are performed by customers of circular offerings to realise their circular potential drawing on social practice theory and its definition of consumption, and using service design mapping tools for identifying the user journey. To realize this aim, an empirical was conducted to analyse the value propositions of companies implementing these offerings. The paper is divided into five sections. After this first introductory section, I develop the conceptual framework used to guide the study. Based on the theoretical approaches, I present the materials and methods for the study in section 3. In the following section, I introduce the findings and discuss them. In the final section, I share some concluding remarks.

2. Conceptual framework

a. Circular economy and offerings

According to the Ellen MacArthur Foundation (2013b) proposal, the economy is divided into two cycles, the biological and the technical. Different actors participate in the value chain and activities associated with them. Such activities must be implemented following a set of principles the Foundation derived from such fields as Industrial Ecology and the schools of Biomimicry and Cradle to Cradle. More recently, other authors have provided more academic definitions, that suggests that a circular economy requires economic activities to be restorative of and decoupled from material use (Ellen MacArthur Foundation, 2013b; Roos, 2014; Webster, 2013).

Following Bocken et al. (2016), a circular offering solves a problem at the same time it contributes to the closing, slowing or narrowing of material flows (refer to Table 1). The Ellen MacArthur Foundation (2013) suggested that re-use, maintenance, remanufacturing, recycling and cascading activities contribute to this purpose. Based on their own definition of the circular economy, Accenture (2014) suggested five solutions that can be considered circular: circular (circulated) supplies, resource recovery services, services for product life extension, sharing platforms and product-service systems. Later and building on Ellen MacArthur Foundation (2015), Lewandowski (2016) proposed, that circular business models are based on four types of offerings: products enabling life-extension, product-service systems, virtualised services and collaborative consumption. In a more recent proposal, Rizos et al. (2017) identified three types of processes, offerings that use fewer primary resources, that maintain the highest value of materials and products, and offerings that change utilisation patterns, such as product as a service, sharing platforms and shifts in consumption patterns.

Table 1 Circular business and product design strategies. Based on Bocken et al. (2016)

Circular business strategy	**Strategy**	**Offering**
Closing material loops	Extending resource value	Recycling products
Slowing material loops	Access-based	Use and Result oriented Product Service Systems Sharing platforms
	Extending product value	Remanufacturing products, consignment stores, swapping
	Classic long-life model	Product-oriented Product Service Systems
	Encourage sufficiency	High-end premium products

The extent to which different types of business models contribute to resource efficiency is a matter of discussion (Vita et al., 2019). In their work, they evaluated the environmental impacts of a wide range of sufficiency and green consumption practices. From their model, the authors estimated that only practices that reduce fashion consumption could significantly reduce environmental impacts, rather than only changing materials. Other authors have embarked in assessing what are the savings resulting from the implementation and adoption of such business models. For example, Iran and Schrader (2017) discussed the different paths through which collaborative consumption models in the fashion industry can support resource efficiency. They suggest that they can contribute to efficiency by intensifying utilisation of products, although as any efficiency gain, it can be subject to rebound effects. Collaborative consumption can also help if a sufficiency effect results from its implementation, i.e. fewer items are demanded. This finding is supported by Farrant et al. (2010) in their life cycle analysis of reusing clothes.

b. Circular consumer behaviours and consumption

Some authors like Hobson (2016), Mylan et al. (2016) and Selvefors et al. (2018) suggest that the circular economy can, and should be approached, not only from a production perspective but also from a consumption one. In line with this argument, Wastling et al. (2018) explored the user behaviours required for the transition to a circular economy focusing on three different types of PSS, based on Tukker (2004). They used their findings to develop a framework for designing products and services that encourage desired circular behaviours. As a first step, they identified a series of desired behaviours for PSS in which the provider owns the product, and the user owns it. They analysed the behaviours for two stages in the consumption process, use and end of use as illustrated in Table 2.

Table 2 Desired circular behaviours. Based on Wastling et al. (2018)

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Consumption phas	**Use and results-oriented PSS**	**Product-oriented PSS**
Use	Adhere to contractual obligations	Establishing a relationship
	Product care	Product care
	Engage with product life extension services	Repair
	Provide information	Engage with product life extension services
	Avoid product misuse	Product attachment/ownership
	Avoid damaging behaviours	
End of use	Fast circulation of goods	Prolong replacement
	Reducing operating costs	Return product
		Sell (via a third party)
		Enable reuse
		Correct disposal/recycling

More recently, Selvefors et al. (2019, 2018) explored what the user perspective on product circularity entailed for design and elaborated a framework to guide designers. In contrast with Wastling, the authors focus more on the definition of consumption and suggest how such understanding can reframe the production-oriented narrative of the circular economy. They suggest consumption is a three-parted process as opposed to one focused only on the purchase of products. Their consumption process is divided into obtainment, use and riddance stages. Products can be accessed or owned. Access can be gained through co-using, borrowing, renting, subscribing, and leasing. Ownership can be obtained via receiving, trading and buying. In a similar way, users can finish co-using agreements, return products, end contracts, offer access, give them up, trade them back, sell them and bring them back. They suggest that what path consumer choose influences resources throughput. What path is chosen depends on how advantageous it is to the user, particularly considering the type of activities the given path entails. Based on this understanding, the authors propose a change in focus from the production to the consumption cycle.

These contributions bring attention to the consumer and user as an active participant in the economic system that can influence how materials and product circulate, a novel approach that is scarce in the existing literature. Although both make significant contributions to this innovative perspective, they also open space for further work. Their understanding of consumption is somehow still limited, as they see it as a two or three-step process. As it is argued in this article, consumption is more nuanced, and the resulting opportunities for intervention can be numerous. From an empirical perspective, and because their main objective was to create a design approach from a user perspective, neither of these studies had access to existing businesses and consumers involved in circular business models that could provide data to assess their suggestions.

c. Consumption moments

Consumption has been explored from different perspectives, including economic, psychosocial, cultural and socio-material (Halkier et al., 2017; Reisch and Thogersen, 2015). In this study, we used the extended definition of consumption offered by Evans (2018) building on Warde (2005). According to Warde, consumption does not happen for the sake of consuming but in the context of social practices. Social practices refer to the set of doings a person's everyday life is made of. Examples of social practices include cooking, showering, travelling, dressing, working, or entertaining. Warde defines consumption not only as the acquisition of objects or services, but also as the "process whereby agents engage in appropriation and appreciation, whether for utilitarian, expressive or contemplative purposes, of goods, services, performances, information or ambience, whether purchased or not, over which the agent has some degree of discretion". (p. 137)

Based on this definition, Evans (2018) suggests that the consumption cycle comprises the acquisition, appropriation and appreciation of artefacts and services as well as devaluation, divestment and disposal. Acquisition refers to how people access objects and services, for example, via purchase, leasing or donations. Appropriation involves the actions by which people incorporate acquired objects or experiences in their everyday life. Gruen (2017) suggests appropriation has the goal to transform the use or functional value of an artefact into sign value, creating a meaningful relationship with the object and it is achieved through creation, knowing and controlling practices. Mifsud et al. (2015), on the other hand, suggests that service appropriation depends on seven dimensions: service knowledge, self-adaptation, service control, service creation, and psychological ownership.

After objects and services are integrated into everyday life, people derive satisfaction or pleasure by using these artefacts or living such experiences, resulting in appreciation. Appreciation results in attachment to the product. According to Mugge (2007), four factors influence the formation of an emotional bond with a product, self-expression, group affiliation, memories, and pleasure. Schifferstein and Zwartkruis-Pelgrim (2008) suggested that product attachment is the result of the product meaning and the different types of the consumer's self. For these authors, product meanings include enjoyment, individual autonomy, group affiliation and life vision each corresponding to a feature of the person: diffuse self, private self, public self and collective self. Table 3 presents some questions that help understand the purpose of each consumption moment.

Table 3 Moments of consumption. Based on Evans (2018), Selvefors et al. (2019), Warde (2005)

Moment of consumption	What people do	Description
Acquisition	How do people access an object?	Co-using, borrowing, renting, subscribing, and leasing (Selvefors et al., 2019)
Appropriation	How do people domesticate an object	Creation, knowing and controlling practices (Grue 2017); Service knowledge, self-adaptation, servi control, service creation, and psychological ownership (Mifsud et al., 2015)
Appreciation	How do people derive satisfaction from an object?	Self-expression, group affiliation, memories, and pleasure (Mugge, 2007); Enjoyment, individual autonomy, group affiliation and life vision (Schifferstein and Zwartkruis-Pelgrim, 2008)
Devaluation	Why do people stop getting pleasu and satisfaction form an object?	As suggested by Evans, and in opposition, at this mome the product or service, stops affording identity, enabli group affiliation, creating memories, and being pleasurable
Divestment	How do people grow detached from a object?	In a similar way, we can suggest that PSS users divest fro it when they stop understanding the service, participati in it, and when they lose control of it.
Disposal	How do people get rid of an object?	Users can finish co-using agreements, return products, e contracts, offer access, give items up, trade items bac sell items and bring items back (Selvefors et al., 2019)

After this process of integration comes the process of expulsion, which is also relevant, especially from a circularity

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perspective. Devaluation, the moment of consumption, when objects and experience do not bring pleasure, joy or satisfaction, losing its value. When a phone stops functioning correctly, as it becomes slow, it loses its value. Or when a restaurant becomes too crowded, it does not provide pleasure anymore, and it becomes devalued. Once objects become devalued, the emotional bond a person develops with a particular 'product specimen' resulting from the meaning they assign to such object, beyond their utilitarian connotation, breaks (Mugge, 2007). Thus, the phone is used less, and alternative options start to be explored, and the restaurant is not visited less frequently. Finally, products and services are disposed of, and they are sent back to the phone provider or forgotten in a drawer (Ertz et al., 2017). By using these moments of consumption and the corresponding questions, I explore how circularity changes what people have to do when they consume goods.

Having an expanded understanding of the consumption process can enable for an increasing number of intervention opportunities for designers and business developers that can improve the user experience and deliver better value (Polaine et al., 2013). Because services gain a more prominent role in this new system, service design becomes a prominent tool for addressing such task as it focuses on understanding people and getting insights about their lives that can be transformed into design guidelines. By incorporating an expanded understanding of the experience, service design can nuance findings and insights. In contrast to product design, service design uses the user experience as the unit of analysis, which is the result of their relationship with the service. In this sense, the quality of the experience depends on the relationships that happen during the use of the service. In the context of the circular economy, understanding what is that experience, is critical to improve it and enable acceptance and adoption. Thus, in this paper we used the user journey tool to map the different actions people using use-oriented PSS for clothing perform as an initial step to understanding how circularity affects consumption.

3. Methods

In order to answer the research question, how circularity influences the consumption process, I use a qualitative research design, investigating the company's and the customers' perspectives on the use journey for a specific type of circular offering, use-oriented Product Service System (PSS). Specifically, I use a multi-case study approach, analysing data from three firms providing this type of offering in the clothing sector. Case study research design allows for an in-depth evaluation of a topic (Eisenhardt, 1989; Stake, 2011). The implementation of digitally based circular offerings, especially in the fashion sector, is quite recent, which limits the knowledge available about how they affect consumption processes. Nonetheless, there are some initiatives that have successfully implemented these strategies that can provide the information to investigate such effects. Thus, these initiatives can be explored as case studies to answer the question. In the following subsections, I expand on what type of cases are used, what data is collected, and how it is analysed.

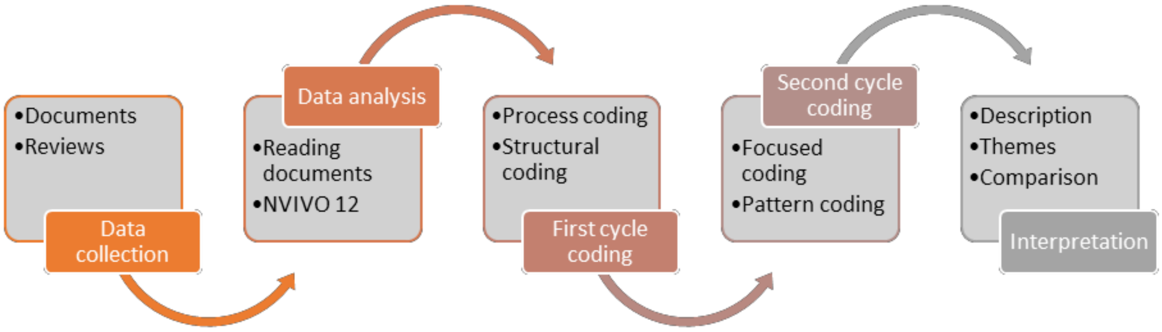

Figure 1. *Research design*

a. Case studies

Based on the definitions of circular business models, specifically use-oriented product-service systems, I looked for companies applying this business model in the fashion sector. In order to secure reliability of the inputs, I chose companies offering subscription services for clothing, founded before 2014. Younger companies may be in a consolidation stage, which prevents the service from being mature. Additionally, I chose companies providing their services online as this offers more accessible information and have a higher probability of growth than locally-based offline businesses. Considering the limited number of companies already offering this service, I followed a purposeful sampling process to choose the cases and focused on crucial cases using critical case sampling, thus selecting decisive examples from which logical generalisations can be derived. Table 4 presents a summary of their main characteristics.

Table 4 Companies used as case studies and data sources

	Company A	**Company B**	**Company C**
Company's documents	Terms of Use, Frequent Asked Questions, website	Terms of Use, Rent agreement, website	Terms of use, Frequent Asked Questions, website
User reviews	80	11	44

b. Data sources

Considering the research question and the theoretical approach, I used data from two perspectives, the company and the customers using the company's documents describing the service and, user-generated reviews describing the journey using the service. Based on such data, I identify the process followed by customers to use the circular offering. Because the research question refers to the process of using the service rather than the experience, these sources were deemed adequate. However, for future research addressing questions about why customers and company address the different stages of consumption the way they do, interviews and contextual inquiry can support deeper insights into the experience and drivers and evaluate to what extent they are connected to circularity.

All companies have been in the market for more than three (3) years with a significant customer base concentrated

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in the U.S. Similar initiatives are emerging in other regions such as Europe, Latin America and Asia, but they haven't reached the same level of maturity.

c. Data collection

Data was collected from the websites and online documents about the service provided by each of the companies analysed. User-generated reviews were mined in 2017 and 2018 with the authorisation of the third-party review site granted in September 2017 via email. Reviews collected were posted between January 2016 and December 2017. User-generated online reviews are a consistent source to investigate consumption-related issues as they met credibility and suitability criteria, especially when understanding the actions followed by the consumer in the context of a specific offering (Camacho-Otero et al., 2019). Other documents such as Terms of Use, Frequently Asked Questions, Rent Agreement were downloaded in December 2018 and updated on June 2019.

d. Data analysis

Data from the different sources were analysed using NVIVO 12 using a double coding process. First, data from documents and user reviews were analysed following a process coding strategy. Having the sub-questions in mind, I coded the documents and reviews using an in vivo approach. This process resulted in 211 coding units. Then, the text strings were clustered in different categories. These categories were then coded following a structural coding strategy based on the research questions and sub-questions presented in the introduction to be categorized under the different moments of consumption. Figure 2 illustrates the process of using the software.

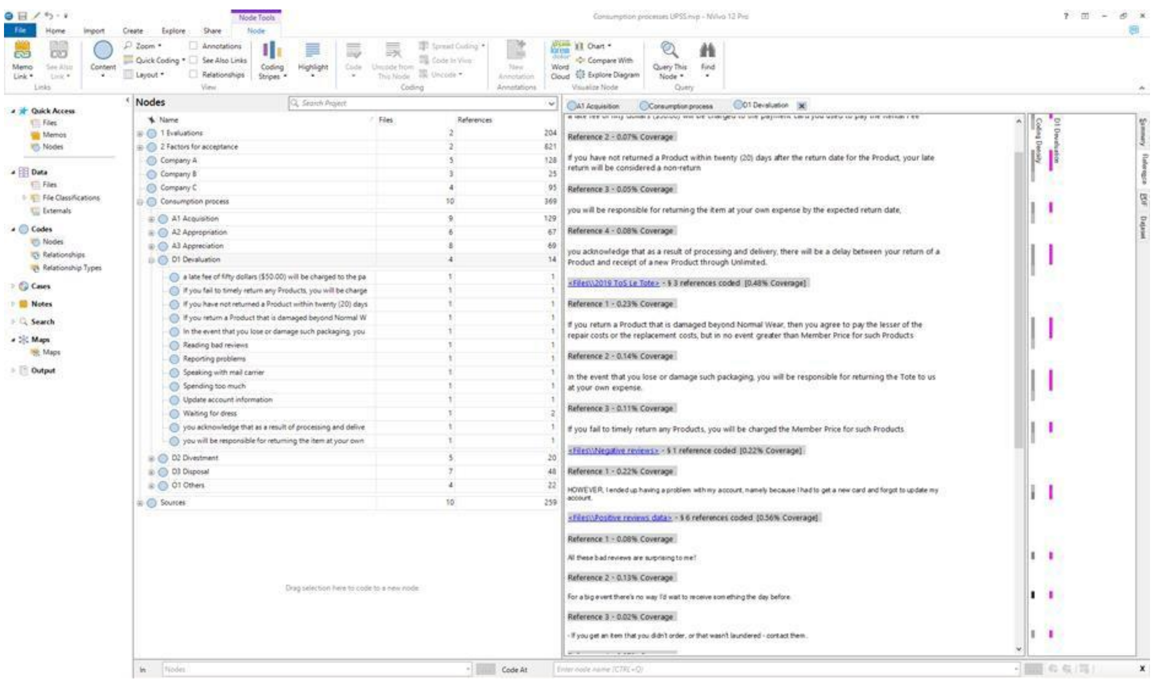


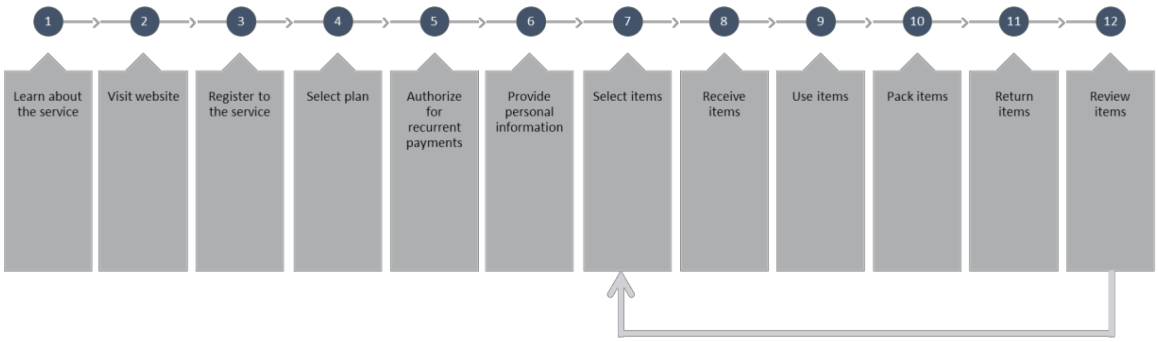
Figure 2. *NVivo 12 analysis tool*

4. Results and Discussion

a. Fashion subscription services

The three case studies offer women's clothing via short term rentals. Figure 3 illustrates the generic user journey for a fashion subscription service, according to the data collected. First, a customer needs to learn about the service. Then she visits the website or any other digital outlet they offer. None of the companies report an offline touchpoint. If the potential customer has made the decision to use the service, she needs to register with the service. Afterward, the user has to select a plan depending on the company and pay the corresponding subscription fee. Once these steps are taken, the user can choose the items she wants to get via mail. The company then sends the items. The user wears the items for as long as she wants. In order to receive new clothes, she needs to return the items, she has using a designated device. Once she returns them, the process starts again with her selecting the new items.

Figure 3. *Generic user journey for a fashion subscription service*



The companies studied are different in the details about these specific steps. Company A owns a stock of items which are available for subscribers. Users choose from this inventory a minimum of 25 pieces from which the company will choose what to select. Users can prioritize items and put others on hold to avoid getting them. Company B asks subscribers a series of questions to define their style and make suggestions for people to choose accessories and garments. Company C offers a subscription service that enables users to pick up to four (4) clothes from the company's wardrobe, which will be sent. For all three companies, people need to send back the items they have if they want to get new ones. There is no time limit for how long they can keep the products if they pay the subscription fee. All cases offer the option of purchasing items. Each company gives users a pre-paid bag to return items. All companies are considered digital as their primary interaction channel with the customer is digital.

b. The consumption process of use-oriented Product Service Systems

Product-service systems have two main components, the product and the service. The product refers to the material tangible part of the offering that the user has access to temporarily. In our case studies, the products are clothes and accessories. The service is the intangible part of the offering to which the user is committed the longest. The service includes the whole experience of accessing garments. Because the relationship between the offering and the user is different for both components, it follows that the consumption processes and the actions that happened in each moment are diverse as well. Figure 4 presents the different actions, users are involved when using the service from a consumption process perspective

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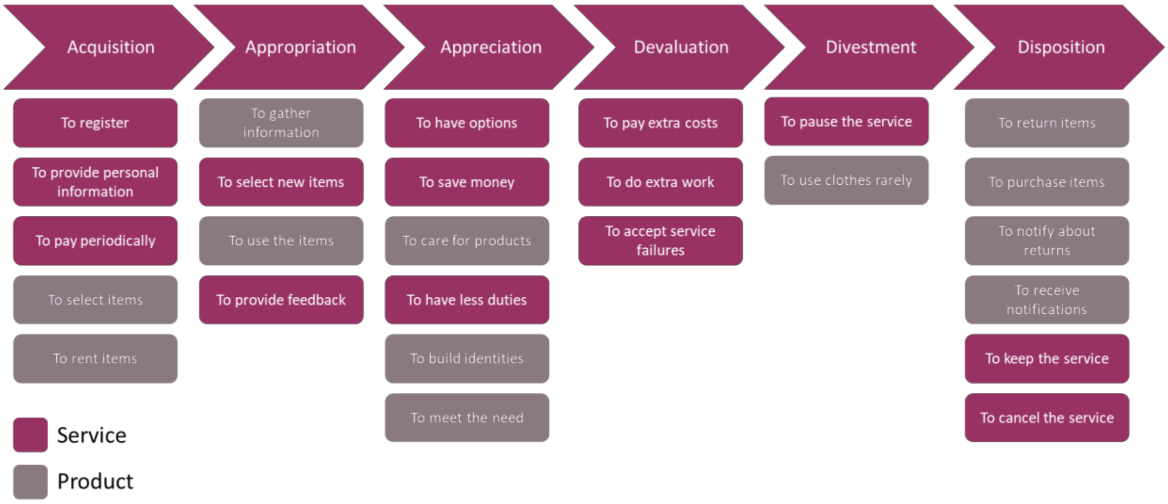

Figure 4. *Actions involved in the consumption process of use-oriented PSS for clothes*

c. Acquisition

In accordance with Evans (2018), consumption starts with the acquisition of the product or experience. In the case studies, items are rented on a short basis. People need to register to access the offering using a device that is connected to the internet. By implication, the service is restricted to people who have access to such devices and have the skills to use them. The registration process requires people to provide different types of information including personal such as shipping and billing address, financial information such as credit card, and information about their individual styles, tastes, and size as suggested by Wastling et al. (2018). This step can have significant implications. On the one hand, people must offer sensitive information to the company. On the other hand, users must be part of formal financial structures and have access to credit, restricting the type of people that can use the service. Once users have completed the registration process, they must select a plan, which in turn defines the price to pay. This price is automatically charged to the credit card given during the registration step and can only be stopped by sending a direct request to the company. These steps are only performed once when the user acquires the service.

In order to access the items, users need to take two additional steps, item selection, and item rental, which happen every time people access new clothes. A fixed number of garments and accessories are selected using the website. In the case of Company A, users have a virtual closet that they need to keep full of items they would like to have:

"Browse our collection of thousands of items from top designers"-Company A

Failing to keep the closet full, can lead to not getting the desired clothes. Company A's users can prioritize what items would they really like to get. Items from all three companies are sent out by the company as rentals and users can have them for an undefined amount of time. However, Company C indicates that:

"If you have not returned a Product within twenty (20) days after the return date for the Product, your late return will be considered a non-return". - Company C

The same company offers the option to get additional items by adding a sum to the monthly fee. In contrast to ownership-based consumption, where people only pay once for the product they want, in the use-oriented PSS models, people pay a recurring fee to access a given number of items over a period. Items within these services are rented, the ownership remains with the provider as presented by Selvefors et al. (2019). Because this is not a traditional way of accessing clothes, people are required to follow the instructions created by the provider. Moreover, the use of the service is personal and cannot be transferred to another person. Finally, this specific type of circular offering can only be acquired by people that meet two criteria, those that have access to digital infrastructures, i.e. computers, smartphones, tablets and the internet and those that are part of the financial system, have positive credit and own a credit card. Thus, poor communities, people that can't or do not want to be digitalized and become part of existing financial circuits are excluded de facto from such solutions, raising equality questions to these propositions.

d. Appropriation

As presented in the theoretical background, the appropriation moment of consumption refers to the strategies the users have to make the offering their own and part of their everyday life. Here again, there is a dual perspective, appropriation of the product and of the service, even though both need to be integrated into the user's daily life and domestic sphere. I identified four main actions that help to appropriate the service and the products. The first action is the act of selecting items repeatedly, which enables service appropriation because as suggested by Mifsud et al. (2015) this affords a sense of co-creation and psychological ownership. For example, users of Company A, need to permanently add items to their virtual closets.

"Just remember that if an item is in your closet, it's fair game no matter what the time of year, so curate your closet frequently and put any out-of-season items that you might want later "on-hold." "- Reviewer Company A

For Company B, users need to choose the items they want for their next box. Although this is an action needed before acquiring the products, via renting, it could be considered a form of routinizing the use of the service, thus a form of appropriation. A repeated enacting of the action can improve knowledge and control, all part of the appropriation process.

"what you tell us in your style profile, how you've rated previously rented items and what is trending—but you choose what you get"-Company B

The second set of actions that enable the appropriation of the service refers to the gathering of information. Users need to be aware of their measurements, read items reviews and based on both, figure out their size. This is not a one-time process as the companies do not offer only one brand and shapes change. Using the service becomes a learning and creating experience about the user's body and the items offered by the company. Also, by having the option of customising the experience, users feel under control.

"it takes some finagling and getting used to in order to be successful in renting pieces for everyday life."- Company C

By using the service regularly, users learn how it works, improve their selection process, and can make it part of their routines. The third set of actions refers to wearing clothes, trying different styles and sizes. Again, these actions give a sense of uniqueness to the service, affording control and creation, both dimensions of the

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appropriation moment described in the literature. Finally, users must review and rate the items they have tried to give the provider information about their experience so they can use it for improving future suggestions. By enabling creation, control and knowing, the service allows users to domesticate it.

e. Appreciation

During the appreciation moment, people derive value from the offering for different reasons. Six themes emerged from the data: having options, economic savings, caring for products, fewer duties, building identity, and product need fit. As indicated by the literature, by offering more options, the offering can create symbolic meaning and contribute to self-expression and individual autonomy (Mugge, 2007; Schifferstein and Zwartkruis-Pelgrim, 2008), as illustrated by this statement:

"I've been able to try styles I would never have tried."- Reviewer Company A

It can also afford to offer flexibility since people don't need to move to a store to access the items. And it also provides functional value to the extent it fulfils the needs of the customer. Because the service provider is responsible for the clothes dry cleaning, customers could save money and benefit economically.

"We professionally clean, sterilize and inspect each Product we send to you." – Company C

Moreover, it is suggested that such a service can help users be in control of what items a user can get. Finally, Company B suggests using the service can help the planet because they are responsible for the washing.

"you're helping the planet by letting us do the laundry." – Company B

At this moment, the dual nature of appreciation is evident, as both the service and the products can provide pleasure and satisfy the user needs.

f. Devaluation

During this moment, the offering loses its value in the eyes of the consumer as a result of different factors. The data shows three elements that contribute to depreciate the service: paying for extra costs, doing extra work, and failing at delivering value. Paying extra costs can be the consequence of late return fees, losing the designated return bag that allows for free returns, having to pay the mailing costs, and being responsible for repairing or replacement costs in case the items are damaged beyond normal wear and tear, as explicitly mentioned in Company C Terms of Reference:

"if you lose or fail to return the RTR carrying case you will be charged $50."

Doing extra work refers to activities that need to be performed to get the best result, and that could be considered additional when compared to a linear offering. For example, users need to read existing user reviews to decide if an item is adequate or not. As they become users, they should write reviews for the company and other users. Users are also required to update their account information. These aspects refer to the service but not to the product. Finally, companies fail in delivering the service when they have problems with logistics or when they give wrong information given the operational challenges of service companies.

"I can't fathom spending $39 on 1 item at a time which takes 7 days to receive." – Reviewer Company A

As suggested by Evans (2018), during this moment, the offering stops providing the benefits that made the user appreciate it. In the case studies analysed here, the economic and functional value of the service failed. We did not find evidence why clothes devalue, though.

g. Divestment

The divestment moment is the result of the previous moment of depreciation. Once the product or the service has lost its value for the current user, there are different paths to be followed. They pause the subscription, or they cancel the subscription. If the decision has been made, and they want to cancel their subscription or extra services, users need to inform and notify providers through different channels, including email, chat, and social media. Regarding the products, people report that they use fewer clothes acquired.

"You may put your Subscription Service on hold for a set period (a "Hold") using "Skip a Month" or "I Need a Break" options in your "Account" page on the Service." – Company B

People using this service do not retain the clothes for a long time, as they are designed for minimizing the time such items are idle by offering free return service and punishing no-returns.

h. Disposal

During this moment of consumption, consumers give up the product or the service. Regarding the product, users return the clothes and accessories to the company using the designated packaging. They can also keep the products and purchase them from the company at a discounted rate. Once people have returned the items, they need to notify the company that they have done so, to expedite the process. Users get notifications from the companies as well to inform them about different matters. Finally, satisfied users keep the service.

"I tried to cancel my membership online, but they no longer allow you to do that, so you HAVE to call and talk to someone who will fiercely try to talk you out of cancelling"

Selvefors et al. (2019) cover cancellation under actions such as finishing the agreement and ending the contract. Return is also considered, but purchasing is not, especially under access-based offerings. This denotes the mixed nature of existing models in the market. Wastling et al. (2018) approach is different and includes fast circulation of goods and reducing operating costs. These can be interpreted as people returning items in a way that helps the company reduce costs.

5. Conclusion

This research investigated the consequences of circularity on the consumption process by analysing the actions involved in each moment of consumption. The study attends to the need to improve the understanding of the circular economy from a consumption perspective to facilitate the acceptance and adoption of specific offerings raised by Kirchherr et al. (2017) and Lofthouse and Prendeville (2018). A first finding suggests that the consumption process involving circular offerings comprises more than three moments, as previously suggested (Selvefors et al., 2019; Wastling et al., 2018). We found that users taking part in use-oriented PSS for clothing perform actions corresponding to the six moments of consumption suggested by Evans (2018) based on Warde (2005) as illustrated in Figure 1. The data also suggests that the actions in each moment differ for the product and the service components of the use-oriented PSS. This study expands the literature on circular consumption by providing a deeper understanding of the circularity implications on the consumption moments.

As suggested by Lofthouse and Prendeville (2018) design propositions to achieve circularity focus primarily on

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the characteristics of the product, but as shown in this study, the user experience around the PSS is also a relevant component influencing consumption, and as such, it should also be carefully designed. The specific actions described in this study can support initiative such as those proposed by Selvefors et al. (2019) and Wastling et al. (2018) for creating design tools that start from the user experience of circular offerings and create solutions that meet their needs and involve resource efficiency. From comparing the three case studies, it becomes apparent that the mechanisms and tasks that contribute to the different moments of consumption in the context of use-oriented PSS are varied but similar among companies. However, identifying tasks and actions for the three initial moments of consumption in the sources was more natural than for the last three. Nevertheless, it is not sufficiently clear if it is because it is easier to get consumers away from products/services or because there is not enough information about the drivers behind these processes.

In sum, this research contributes to an analytical framework and empirical data to characterise such a question in the context of use-oriented PSS in the clothing sector. Future research can focus on how circularity influences each of the components of use-oriented PSS in different sectors. Finally, the data sources for this study are limited, hence, constraining the level of detailed achieved. Thus, future research can broaden the scope of data sourcesto populate some of the insights offered here. Moreover, it is suggested that new studies focus on how circularity influences each of the components of use-oriented PSS in different sectors. This research has several limitations. First, as it has focused only on one type of circular offering for one specific sector and it will be relevant to explore how the different moments of consumption express for different sectors and offerings. Second, further conceptualisation about the type of activities and consequences on how businesses are structured in the context of the circular economy is needed. Third, by using three case studies, the generalizability of the findings is restricted. These shortcomings should be addressed in future research exploring circular business models and consumption.

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Unleashing Island Mode: Utilising Smart Energy Systems approach to ease regulatory constraints on renewable development.

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Abstract

Recent reports from IPCC Special Report and the 4th National Assessment state unequivocally that current practices lead to massive disruption from climate change effects. Perversely, all the solutions required to achieve a sustainable <1.5°C are widely known, yet roadblocks exist that prevent their widespread implementation.

A large and complex part of this problem is the regulatory environment. Often, legacy regulations from an era before the magnitude of the climate crisis was fully understood prevent projects from proceeding. With renewable energy, dealing with the intermittency problem is the key to removing these roadblocks. Designing systems that are not connected to the grid is an effective way to sidestep these roadblocks however, designs need to be employed carefully, such that critical excess energy and reliability of supply issues are effectively dealt with internally to the project.

This is a proof-of-concept study for the design and implementation of a large-scale solar installation in Ghana, where negotiating a power purchase contract with the electricity company monopoly has prevented all except their own solar installations. European companies, that own and operate business units in developing countries, can lead the move to lower the embedded CO_2 content of aquaculture protein, increase the reliability of operations, and allows MW scale solar to be installed in a comparatively low regulatory environment. The study shows an attractive return on investment with no subsidies and no connection to the grid which could potentially remove obstacles to rapid development and create a low embodied carbon content market advantage.

Keywords: Smart Energy Systems, Off-grid, Island Mode, Solar, Renewable

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1.Introduction:

In developed economies, lobbying from traditional energy sources like coal, oil, and gas and misinformation regarding CO_2 emissions has retarded development of renewable energy sources (RES) (Marques, Fuinhas, & Pires Manso, 2010). Since that research, public policy has typically been slow to change, leading to an unprecedented urgency for policy makers to act (IPCC, 2018). Our pathway for the future relies upon a radically increased capacity of wind and solar, combined with a smart energy system (Mathiesen, Lund, & Karlsson, 2011). However, RES such as wind and solar are inherently intermittent. When intermittent RES is replacing base-load thermal generation, there is a threat to grid stability during periods when there is a lack of supply, or critical excess energy. Many network operators are investing in smart energy systems where critical excess energy can be stored in a heating or cooling networks, pumped hydro, converted to hydrogen, or otherwise stored (Zame, Brehm, Nitica, Richard, & Schweitzer III, 2018). There is a clear distinction of the technologies across the capacity scale and grid connectivity. Where RES is easily connected to a grid then the grid often acts as a virtual battery (S. S. Sami, M. Cheng, J. Wu, & N. Jenkins, 2018). When remotely located relative to an existing grid, then microgrid architectures take precedent.

Electricity grids are very large and complex infrastructures which must be in a state of balance at all times. For any given second, the total load on the grid should be matched by the supply, otherwise frequency and voltage depart from the quality standards and safety margins. Grid operators are responsible for coordinating the balance, while the specific department (balance responsible party) rely on several tiers of control. Primary, Secondary, and Tertiary reserve refer to the response time for the variable production or load, control vested in the balance responsible party (Nordpool 2019). This complex system is built on monthly forecasts, day-ahead tenders for supply, and active live wire management. It is this legacy architecture that gives rise to the intermittency problem of renewables and the cost of providing back-up supply (Heal, 2009). It is also the main reason why there are many restrictions on who and how technologies can be connected to the grid. In Europe, in order to install renewable, one must first establish a power purchase contract with the balance responsible party (Klessmann, Held, Rathmann, & Ragwitz, 2011; Sarasa-Maestro, Dufo-López, & Bernal-Agustín, 2013). A power purchase contract or feed-in tariff has been shown to be the most effective incentive structure as the cost can be shared or passed on (Sarasa-Maestro et al., 2013). In countries such as Denmark, where such a power purchase agreement offers a low purchase price from the balance responsible party, the low incentive results in slow deployment rates for the technology. In markets like Germany, higher prices have stimulated deployment (Czada, 2018). Specifically in Germany's case, the rate of return for an investment in solar was over 10%, while in the UK it was around 8% (Sarasa-Maestro et al., 2013), the difference making Germany the world leader in Solar photovoltaics in 2010 (Frondel, Ritter, Schmidt, & Vance, 2010). Nicolini and Tavoni (2017) have quantised the incentive where a "1% increase in the subsidy can lead to 18% - 26% in renewable generation" (p. 412). Such responses are the result of EU Directive (2009) setting a target of 20% share of Renewable energy by 2020. However recent policy documents from the IPCC (2018) express that the world should aim for 100% renewable fraction by 2030. Clearly achieving such high levels of renewables integration is causing balance- responsible parties to rethink their strategies and look for innovative ways to support the inclusion of higher shares of renewables.

In recent years, grid operators have sought to improve their ability to manage and control their grids with smart technologies. These technologies require that operators break from traditional communications-based smart solutions (Zame et al., 2018) and look towards a smart energy system incorporating a dynamic interplay between the heating and cooling demands, transport, and energy conversion technologies (Mathiesen et al., 2011). This interplay also considers variable demand systems that can perform an energy storage function by delaying work output until there is ample renewable supply in the system, such as sub cooling a freezer or load- shedding (Aghaei & Alizadeh, 2013; J. S. Vardakas, N. Zorba, & C. V. Verikoukis, 2015; McPherson & Tahseen, 2018). These types of control and virtual storage techniques can be collectively called Demand Side Management (R. Deng, Z. Yang, M. Chow, & J. Chen, 2015; Siano, 2014; X. Zhang, G. Hug, J. Z. Kolter, & I. Harjunkoski, 2016). While all these developments are constructive, there is a third perspective, that is to combine renewable technology installations with a load that can completely absorb the installed peak capacity and has inbuilt storage or demand side management to cope with the intermittency. If designed and installed, these systems would be able to be off-grid and therefore not contribute to grid operators' concerns, or the issues of intermittency and unreliability. Furthermore, such systems would not be able to benefit from the incentives that are meant to encourage renewable energy installations and therefore must be commercially financially robust.

It is in this context that this paper takes its departure from current research and reference. Presented is a case study for a modelled large-scale solar photovoltaic installation that is hypothesised to be completely off-grid. Operating in island mode, the whole installation must be able to completely store all the energy within a self-contained system and deliver high reliability. A financial return on investment is calculated for the proposed plant showing its attractiveness as an investment for European companies operating in sub-Saharan Africa (SSA) and a case for a demonstration-scale pilot project is made.

2.Background to the case:

The European and Danish context forming the background for the author makes it difficult to envisage how such technology may be integrated for industry. There are no European examples of large-scale renewable installations not connected to the grid. Scale is the key differentiation in this case, as by 'large-scale' we mean above 3MW installed capacity. An exhaustive literature review finds no academic consideration of any large- scale solar or wind not connected to a grid. Even for remote communities, island mode recreates the grid structure in miniature, so called microgrids, which are controlled and managed by the balance responsible party (Hirsch, Parag, & Guerrero, 2018). Many microgrids may scale up to 10MW however, this is normally consisting of distributed generation assets, and a diversity of supply. The issue we attempt to tackle here is a large-scale 3MW photovoltaic system supplying a single demand and absorbing all the energy while developing a storage resource capable of delivering base load. The key to unlocking the base load conundrum is to remember that energy is not only electricity. Due to the legacy of the grid-connected nature of our daily experience, we tend to consider electricity the only form of useful energy. The development and description by Henrik Lund and others (2010) on the smart energy system, takes advantage of the fact that heat and cooling loads can be easily stored and used and are efficient when the additional step of returning the lower order storage medium back to electricity (high order) is eliminated. Therefore, industrial loads requiring direct heat for example can use the storage medium directly. District heating is a common and well researched example of this practice (Lund 2010).

To place intermittency in context of this case, there is a subtle difference in RES, whereas wind production is completely unpredictable, solar is predictable but unreliable. The importance of this only becomes significant when considering which energy matches which load for an off-grid application. Storage must have the capacity to reserve enough energy for periods when renewable production is lowest. The global search is on for industrial loads, located in areas with a predictable but unreliable renewable energy supply. The latter is simply solar, and

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the former is aquaculture.

3.Case Study:

Aquaculture is the growing of seafood protein in controlled conditions. Farms can be nets in the sea, or tanks on land however; in that case, recirculation of water is extremely energy intensive. Aquaculture is currently undergoing a boom with growth approaching 14%. The UN FAO report (2016) states that;

> *"In 2014, fish harvested from aquaculture amounted to 73.8 million tonnes, with an estimated first-sale value of US$160.2 billion, consisting of 49.8 million tonnes of finfish (US$99.2 billion), 16.1 million tonnes of molluscs (US$19 billion), 6.9 million tonnes of crustaceans (US$36.2 billion)…" (p.17).*

This is the fastest growing primary production sector, and "…aquaculture growth is offsetting a declining wild resource and supports total fish protein consumption growth" (p.18). That the ministry of agriculture in Saudi Arabia intends to open 20,000ha of the Red Sea coast to new aquaculture production (MEWA 2019) is a testament to this growth. The aquaculture that is interesting to this case is land-based shallow ponds for a wide variety of pelagic and crustacean species. The fish grow out in these ponds and critical to the enterprise's success is water chemistry, cleanliness, temperature, and high reliability. Recirculation is typically carried out by paddle wheel oxygenators, which both serve to add dissolved oxygen and move the water physically for mixing. Such farms are located where typically there is access to low cost land, a reliable grid for power supply, good logistics for feed supply and less strict emissions and pollution regulations, or poor monitoring and enforcement. Hence, many of these farms are located in SSA and South East Asia (SEA), which both generally offer fairly high solar radiation figures and access to an emerging land market (Sjaastad, 2003). The rapid growth in this industry has attracted corporate entities from developed countries, which are able to access the large capital investments required to turn marginal agricultural land into RES for aquaculture farms.

The case in question is located in the Volta region of Ghana, West Africa. It is owned by a large European corporate owner who has developed 100ha, but has plans to expand to 1000 ha within the next 5 to 10 years. The Volta region in Ghana has excellent solar radiance averages (Acheampong et al., 2019). The farm location is on flat ground, with a localised brush cover enabling laying the panels flat and on the ground with no shading.

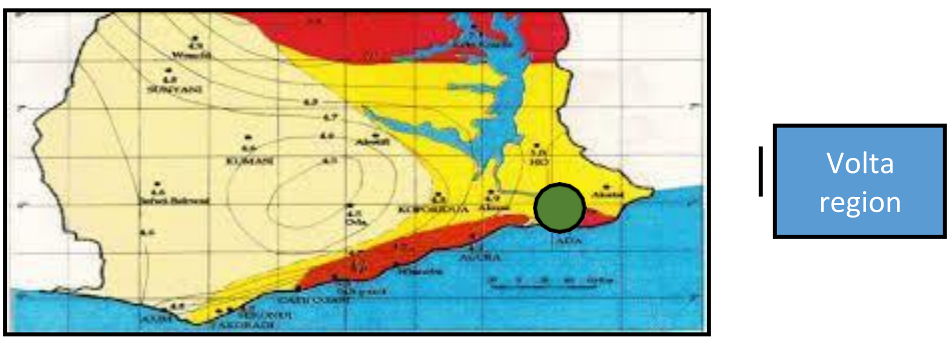

Figure 1*: Solar radiance for Southern Ghana, Volta region circled in green (Acheampong et al., 2019).*

The farm comprises 50 ponds of between 400m2 to 1600m2 on either side of a central irrigation canal.

***Figure 2**: Aerial photo of case study site.*

The farm is connected to the local grid, which supplies electricity for an average of 70% of the time due to a brownout load management strategy (Batterberry, Miller, Jaskolka, & Toll, 2010). Although the grid is estimated to be the third most developed in Africa and reached 55% of the population in around 2011 (Kemausuor, Obeng, Brew-Hammond, & Duker, 2011) and an estimated annual growth rate in energy demand of 13.9% (GRIDCo, 2017). This rapid growth has led to a system that is severely demand constrained as evidenced by frequent loss of supply for control reasons. The grid is dominated by coal-thermal and hydro resource, which makes it vulnerable to climate fluctuations, where in periods of lower rainfall, the grid has a large shortfall as turbines at Akosombo dam are shut down.

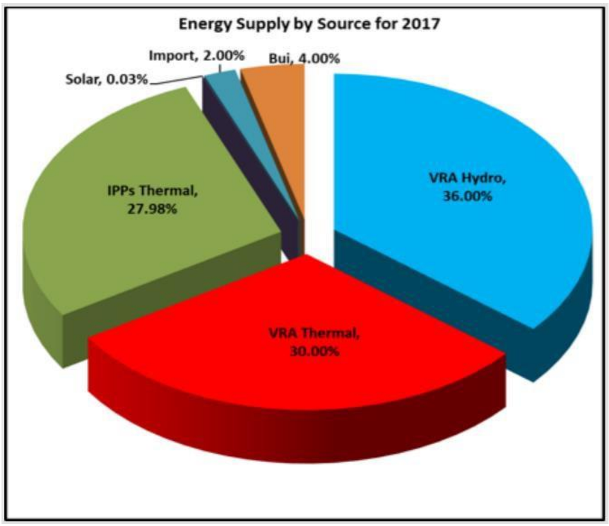

***Figure 3**: 2017 Energy Supply by Source in Ghana.*

As shown, the installed capacity of solar generation is insignificant (0,03%), however in recent years, the installed capacity has increased an order of magnitude with a 20MW plant being commissioned in late 2017 (Zhang, Adu, Fang, Ofosu, & Oppong Kyekyeku, 2018) not included in that data.

To understand why there has been so little activity in solar renewables, we must show a quick overview of the

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policy history. A major strategy implementation called the "Golden Age of Business" was focused on; improved availability, accessibility, and affordability [of electrical energy] with a special focus on rural areas (NDPC, 2007). This strategy focused on rapid development and base load to the detriment of emerging technology due to a continued ability to hide the social cost of carbon (Nordhaus, 2017). Several public strategies were not formally adopted due to political machinations however, the Ghana Energy Development and Access Project (GEDAP) was. GEDAP is a multifaceted project involving the World Bank, International Development Agency (IDA), African Development Bank (AfDB), Global Environment Facility (GEF), Africa Catalytic Growth Fund (ACGF), Global Partnership on Output based Aid (GPOBA), and the Swiss Agency for Development and Cooperation (SECO). GEDAP's objective is to improve the operational efficiency of the power distribution system, increase the access to electricity, and help transition Ghana to a low-carbon economy by lowering greenhouse gas emissions (World Bank 2015). Concerning electricity access and renewable energy development is component C of GEDAP costing US$101.5 million. This component has three sub-components: the multifaceted approach, grid extension, and isolated grids.

While these policies and initiatives have led to growth, the lowering of carbon emissions has not been achieved. Grid energy related emissions have grown 14.9% during 2012 – 2016 (Pwamang, Appah-Sampong, & Oppong-Boadi, 2019). The primary roadblock to rapid development for renewable energy has been the inability to obtain a power purchase contract with the balance responsible party to make a project bankable. Anecdotal stories in development circles that several companies have been unsuccessful to realise potential projects, even though they own land, while not having significant evidence, tend to support the lack of solar projects in the country.

Finally, at the site the grid energy is supported by diesel generator backup systems that run about 250 hours per month, representing 30% of the total electricity load. The fish farming operation requires a constant supply of electricity to operate the paddle wheel oxygenators and due to the high stocking rates in the ponds, loss of power for a few hours will lead to losses. Currently the farm is operating on about 70% redundancy because for substantial periods the diesel generators work with no other backup. Clearly, any renewable solution should have a higher safety factor to be acceptable to the aquaculture industry.

The scenario envisages installing solar photovoltaic panels, which will supply energy to pumps that will raise water to a holding tank. Recirculation is provided by a slow release of water back to the ponds via venturi oxygenators, which will both efficiently oxygenate the water and mix similarly to the existing paddle wheel devices. The advantage of this system is that water can be stored in volume to provide redundancy to the system. Further, the system should be able to store all the energy provided by the solar panels and therefore does not need to be connected to the grid. The hypothesis under scrutiny is if the high capital cost of providing this system ensures the farm with a lower energy cost in the long term. The ability to predict energy conversion from photovoltaics is well understood however, the massive volume of storage required is not viable when considering photovoltaic under existing feed in tariffs, as evidenced by the low solar capacity installed in the country to date.

4.Methodology

A scenario optimisation model was created to frame the proof-of-concept study. With a fixed location many variables can also be fixed. The fixed variables are solar radiation, existing energy costs, and a technology selection. The model utilises hourly weather data collected from the ERA5 Solar radiance station dataset located

12 km away from site (DLR, nd). The site is located close enough that variance from this dataset would be negligible on a longer-term calculation. The current energy costs are intended to be 100% offset by the new scenario, so a monthly average lump sum cost is taken and fixed forward for the lifecycle of the scenario. In this way, the farm owner utilises cost offset at a retail price to calculate savings to pay off capital costs of the installed equipment. This can be reformulated into the levelised cost of energy (LCOE), which is a lifecycle cost calculation extended over the lifespan of the equipment. The lifespan is currently set at 20 years as an arbitrary number however; it represents adequate time to calculate a positive outcome of the scenario and falls well within the expected life period of the equipment. The first variable is operational strategy, where the model allows either increase or decrease storage depending on farming load and harvest schedule. An overview of the variable inputs to the model are given in figure 4.

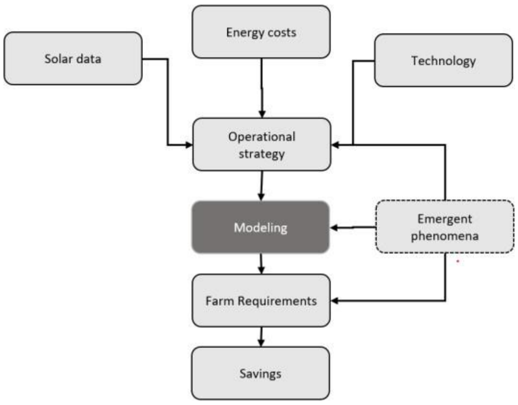

Figure 4: Flowchart of scenario model

The Model considers the fixed cost inputs and operational strategy however, there is expected to be emergent phenomena created by subtle control of recirculating water over the on-off state of single paddle wheel oxygenators. In addition, ponds can share resources so peak loads can be spread over the resources of two or three ponds.

The calculation of LCOE is a simple sum of the fixed and operational costs, less savings, and discounted for the future social cost. Being relative to time, LCOE tends to lower over longer time scales.

LCOE is calculated

$$LCOE = \frac{\sum_{t=0}^{n} \frac{I_t + A_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{M_{t,et}}{(1+i)^t}}$$

Equation 1

Where I_t = Investment (or capital) costs and A_t = Annual total costs in year *t*. This is divided by $M_{t,}$ = Produced quantity of electricity in the respective year in kWh. The LCOE represents the actual cost of the energy supply, accounts for the capital costs and the operations, and maintenance costs per unit of energy. It provides a basis for comparing energy supply over a longer period. i = the discount rate, a financial operator that expresses the future social value of money. The discount rate is taken from recent renewable comparison research by Pueyo, Bawakyillenuo and Osiolo (2016). Finally, n = operational lifetime in years and t = year of lifetime (1, 2, ...)

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The Net Present Value (NPV) is a financial tool for measuring the future revenue streams. The calculations sums over time and a social discount rate is applied.

NPV calculated $$NPV = -I_0 + \sum_{1}^{n} \frac{c_i}{(1+r)^i}$$ ***Equation 2***

In Eq. (2), *NPV* is net present value. I_0 is the initial investment in period zero (positive number shown with a minus sign to indicate that money is paid). The c_i represents the cash flow over periods i = 1 to n (positive to reflect money received, or negative to indicate additional investment). Finally, r is the cost of capital or discount rate and n is the number of periods. The NPV is taken rather than an IRR as a basis for comparison due to the more nuanced representation in the shorter time periods or higher rates of return (Osborne, 2010).

The solar, pumps, and pond equipment is selected based on two criteria, strong guarantee on performance and demonstrated performance in harsh conditions. Grundfos manufactures a solar and water pumping system ready to install in remote locations. The technical specifications available for pump performance are well backed up with real world experience (Beswick, 2018).

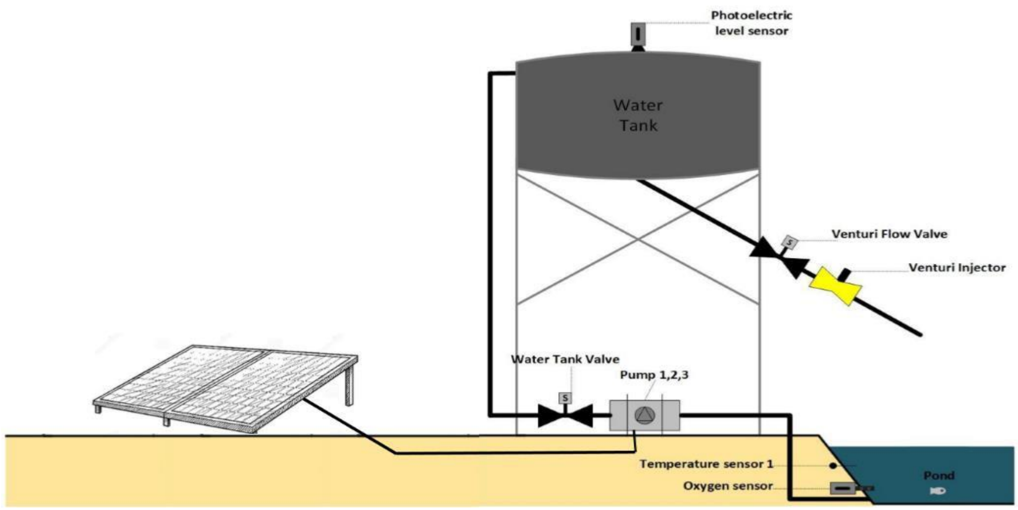

Figure 5: Schematic layout of modelled equipment

5.Results

Data regarding solar radiance reflects the prime location for the proposed installation, where actual water pumped to storage is highly correlated with a linear coefficient (R^2 value 0.9555), indicating less than 3 days per year with a true shortfall. This indicates a safe predictive value for pumping water is the lower quartile of daily figures, which will actually cover over 95% of the load because of demand management. Storage should cover

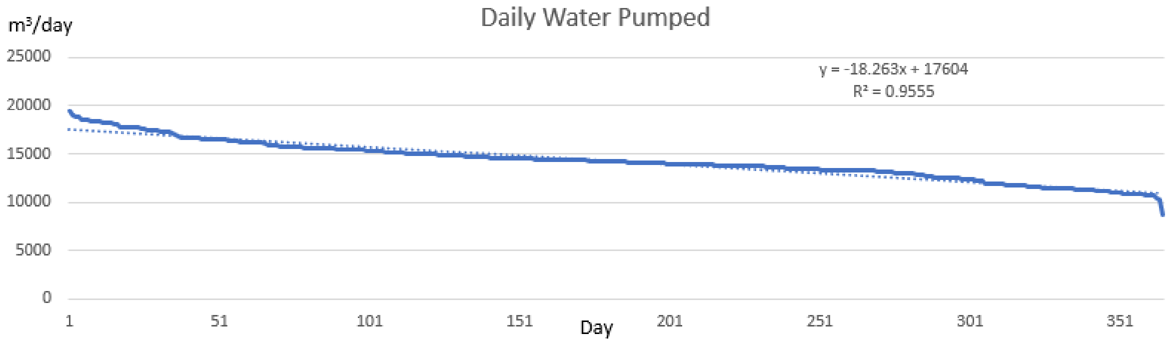

Figure 6: Daily water pumped in scenario arranged according to solar radiative energy available.

production shortfall on all days. When the data is arranged by calendar, the hourly variance is covered by storage fluctuations. The sensitivity of storage is around 25% reserve capacity where there is ample to cover production fluctuations however, for redundancy, storage is manually set at above 50% which covers severe weather events.

The large water volumes require a massive storage capacity. Currently planned are 710 *x* 30m^3 plastic tanks and associated piping, which will occupy much of the bund area available. The upfront costs are an order of magnitude larger than the cost of the solar so from the outset it is not clear if this is a viable business strategy.

The NPV is 9% for a 3MW solar installation feeding the 100ha farm completely replacing paddle wheel oxygenators energy stored in 710 tanks. This includes a discounted future value of income over 20 years of 4,6%. The viability of the project is highly sensitive to the social discount rate, more so than a hybrid diesel system for example, due to the fact that operations and maintenance costs are low enough as to be negligible, whereas, fuel costs for the diesel alternative are discounted into the future along with return on investment (Appiah, 2018).
The year on year levelised cost of energy ($LCOE_{yr}$) is calculated at 0.1345 €/kWh which is a high price compared to coal, wind, or solar projects because none of those technologies are off-grid. Comparing the LCOE against the quoted figures for solar industry in general (ENS 2019) reveals the reality that the express difference in the sum is the cost of storage. The scenario comparison is made over the LCOE versus the current energy costs, and since the scenario is based on an off-grid model, the retail price of energy is the correct number to compare to. Thus, the farmer has a current energy cost of 0.2047 €/kWh grid costs and 0.2237 €/kWh electrical from the diesel back up. Both of these numbers also include the cost of storage, i.e. the diesel stored in fuel tanks or the water in Akasombo dam so there is a year on year saving to be made however, if this is discounted using a high (10%) social discount price, the scenario is marginal

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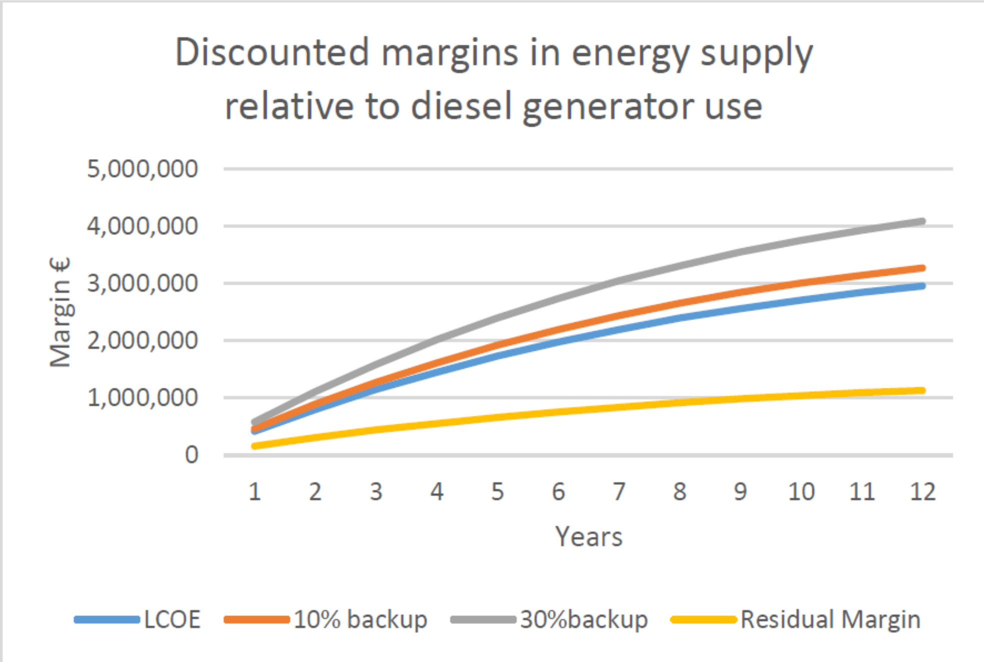

Figure 7:LCOE of scenario and residual margin on current costs.

The true LCOE, i.e. the price including the whole lifecycle (20yr), emissions, and the costs of the intermittency problem paid for up front is 0.0440 €/kWh. This price is comparable to many new technologies and only slightly above the marginal cost of coal energy in most grid systems (Lund et al., 2010). This lifecycle LCOE reflects the low operation and maintenance of the water storage system and the efficiency (100%) of retrieving the energy from storage in this scenario. The scenario omits the cost of land and rent, permissions, taxes, and the research and development phase of a demonstration installation.

6.Discussion

The scenario shows that the system is viable, increasingly in situations with a poor grid services because the diesel back up only increases the margin if used more often. The system would be more reliable than the existing technology with flexibility created by sharing the storage however, that will have emergent properties and are difficult to predict. The cost of buying the storage at scale enough to absorb all the power and enable off grid is high however, the scenario draws its strength on the assumption to fix long term income by keeping current energy charges fixed forward.

This scenario becomes an attractive solution where there is a desire to act quickly, fix future costs for a long- term energy hedge, increase reliability of oxygenated water supply, and reduce the embodied content of CO_2 to near zero of aquaculture protein production. The ability to act quickly is facilitated by the regulatory environment where the scenario eliminates the need to negotiate a power purchase contract, and substantially removes many complex contractual negotiations regarding prices, capacity and connection charges obligatory under the Ghanaian ACT 382, the Renewable Energy Act (2011). The low operations and maintenance cost make the long-term viability highly attractive. The elimination of connection equipment, control, and monitoring also reduces the costs however, the cost of storage is very large, so the scenario was not sensitive to fluctuations in these numbers. The main advantage for making this investment is the ability to do it without negotiating a feed-in-tariff with the local grid operator and balance responsible party meaning that the entity may commence immediately and provide a long-term income expectation that would satisfy most commercial lenders.

The off grid framing of the scenario has another intangible benefit. The large savings in CO_2 offset by using solar in lieu of the grid energy in combination with diesel generators will only accrue to the fish stock and cannot be booked to the grid operator's energy portfolio. This externality is relevant given this quote from the latest World Bank report (2014);

> *"At the World Bank, we hear from the heads of major seafood companies that they want to secure access to reliable and environmentally sustainable supply chains. Matching growing market demand with this private sector interest in reliable and sustainable sourcing presents a major opportunity for developing countries prepared to invest in improved fisheries management and environmentally sustainable aquaculture." - Juergen Voegele, (p, vii).*

7.Conclusion

The scenario indicates that the LCOE figure of 0.044 €/kWh would be an acceptable price to pay for Corporate aquaculture owners to deliver CO_2 neutral protein. The high cost of the storage up front requires a robust long-term contractual obligation to pay for energy. This can be negotiated directly with the corporate aquaculture owner (as a long term energy costs hedge) and not the grid operator or balance responsible party. The return is highly sensitive to high social discount rate.

The scenario exposes weaknesses in the available science such as the effect of operational response, load sharing, and predictive management of the farming operations which could enhance the performance of the storage and improve returns. It would only be possible to measure such effects by way of a 1:25 scale demonstration project.

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Paper Chain. New market niches for the paper industry waste based on circular economy and sustainability approaches

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Abstract

Europe ranks second in the world in Pulp & Paper products and generates around 11 million tonnes of waste annually. The paperChain project, funded by the programme Horizon 2020, aims at creating new markets for different Pulp & Paper waste streams by upcycling and creating secondary raw materials for other resource intensive sectors. Five circular cases are deployed all over Europe to demonstrate the technical, socioeconomical and environmental feasibility of the solutions carried out, within building construction, road and railway infrastructure construction, chemical industry and mining sector. Moreover, the sustainability of the new products and solutions developed must be assessed and compared with that of existing ones, to be validated in the framework of the European Circular Economy Action Plan. On the other hand, any sustainability assessment of the project must consider, at least, the evaluation of environmental, economic and social aspects under a life cycle perspective. This method has been identified as the most appropriate to be applied in this kind of assessments, to ensure that there is no impact shifting between different impact categories, different areas or different stages of the life cycle. For these reasons, the selected methodology has been Life Cycle Sustainability Assessment (LCSA), consisting on the realisation of three individual life cycle assessments of the environmental, economic and social impacts of the developed products, according to the guidelines proposed by UNEP/SETAC Life Cycle Initiative in 2011 Towards a Life Cycle Sustainability Assessment: Making informed choices on products. The first circular case was implemented in Spain in the last quarter of 2018, implementing new solutions to the road construction sector. Waste Paper Fly Ash (WPFA) is a waste stream generated in energy recovery plants to produce electricity from rejects of paper recycling process that cannot be recycled anymore. This ash has been used to replace lime in a stabilised subgrade layer of an unpaved road and to replace cement in a stabilised subgrade layer of a paved road. In parallel with the technical validation of these solutions, the sustainability assessment of the deployed innovation actions must be assessed applying the LCSA methodology, in direct comparison with the existing products and implementations. The paperChain project will be able to demonstrate the feasibility of applying ecoinnovation into new business models from waste streams generated in the Pulp and Paper Industry in Europe, decreasing the amount of waste disposed to landfills in a sustainable way of acting.

Keywords: Sustainability, Circular Economy, LCA, Roads, Pulp and Paper Industry

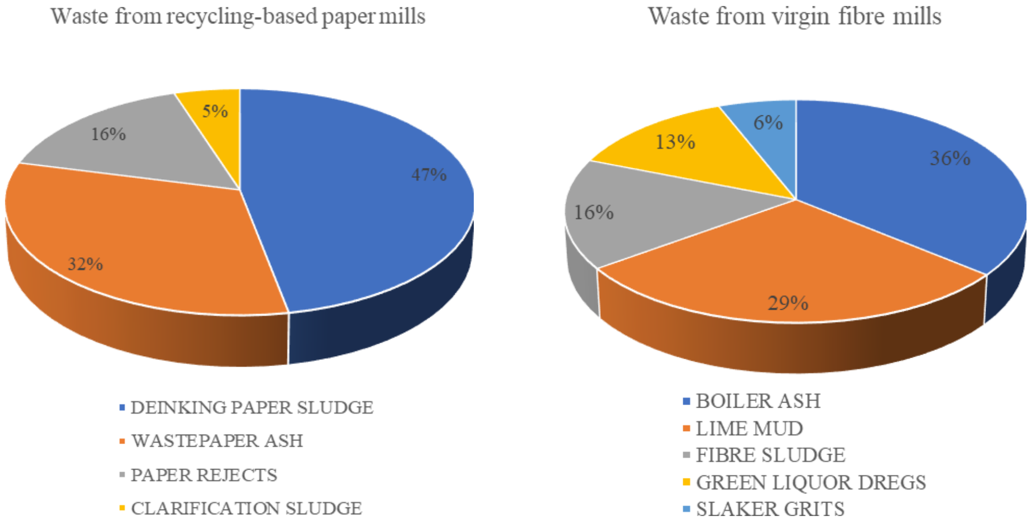
1. Introduction

One of the main strategies European Commission has adopted to face sustainable consumption and production has been the Circular Economy Action Plan, which is focused in one of the biggest concerns related with SCP, the efficient use of material resources. Between the different objectives of this action plan the research of waste flows in any industrial sector which can be used as secondary raw materials is one of the most relevant ones.

paperChain project, funded by the European Commission under the H2020 programme, brings in an industrial symbiosis model centred in the use of different waste streams generated by a resource intensive sector, the European Pulp and Paper Industry, as valuable feedstock for three resource hungry sectors: the construction sector, the mining sector and the chemical industry.

Different waste streams are produced as a result of the manufacturing processes of the Pulp and Paper Industry to produce paper, board and other cellulose-based products. Pulp can be obtained from wood virgin fibre by chemical or mechanical means, but it is also produced by the re-pulping of recycling paper which accounts for about 50 % of the fibres used and involves cleaning and deinking processes (Suhr, M. et al., 2015). As Figure 1 shows, the most important waste streams in terms of quantity are ashes, sludge and lime mud.

***Figure 1**: Data for year 2013 from BAT modified with data from (Bird,M. and Talberth,J., 2008)*



paperChain tackles the valorisation of almost the totality of these PPI waste streams. The project focuses on those waste streams whose current fate is mainly landfilling, such as the causticizing residuals, and those which are produced in major quantities, such as sludge or ashes. Only boiler and furnace ash has been discarded due to their potential as fertilizers, in favour of wastepaper ash, much more promising for the construction sector.

In the last years, many companies of the Pulp and Paper industry have built and operated energy valorisation plants (CEPI, 2019) that burn sludge paper waste produced in their paper mills to generate the heat and electricity they consume. Consequently, a big amount of fly ash and bottom ash are produced every year, being all of them disposed to landfill.

Waste paper fly ashes have demonstrated their validity to be used as a binder material in the construction sector (Mazouak, M. A. et al., 2010, Monosi, S. et al., 2012, Segui, P. et al., 2012) and therefore this is a good candidate to become a secondary raw material for the road construction sector and to develop new circular economy business

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models. At this respect, some research has been done in the application of this kind of materials for the construction of paved roads but there is a gap in studying their application on unpaved roads as rural service roads (Balaguera, A. et al., 2018) which represent a significant part of the road infrastructure in any country.

On the other hand, any new circular economy solution must demonstrate its sustainability prior to being adopted and implement. This means that they must be at least as sustainable as conventional solutions and preferably, they must have lower environmental and social negative impacts, lower costs and higher social benefits.

At this point, life cycle sustainability assessment (LCSA) (Ciroth, A. et al., 2011, Klöpffer, W., 2008) has become a reference methodology to evaluate the sustainability of any system (product or service) taking into account its life cycle as it helps to define the conditions in which environmental life cycle assessment ((e)-LCA), life cycle costing assessment (LCC) and social life cycle assessment (s-LCA) have to be done in a coordinated way so any impact trade-off between the three dimensions of sustainability or between life cycle stages or processes can be account and assessed and therefore, the decision making process could be accurate and correct.

2. Methods

2.1. Use of WPFA from the pulp and paper industry on road construction

The laboratory work started with the characterisation of the intervening materials: WPFA and soil, through a series of studies that confirmed the viability to proceed with the mixture of both materials. Physical, chemical and mineralogical properties were determined in order to define the job mix formula and ensure that it meets the requirements of the Spanish Specifications for soil stabilisation with lime.

Main components and cementitious properties of these ashes were determined through density, particle size analysis, X-ray diffraction and X-ray Fluorescence. Regarding the soil, the tests carried out were: gradation, Atterberg limits, organic matter content, Modified Proctor test and California Bearing Ratio (CBR).

The job mix formula of the solution to be used in the demonstrator consisted in defining a combination of soil and WPFA meeting the same requirements requested for the stabilisation with lime, which are shown in Table 1. Hence, a reference formula with the conventional stabilisation of soil and lime was also defined.

Table 1: *Properties to be fulfilled by a conventional stabilised soil with lime*

Property	Unit	Value
Californian Bearing Ratio (CBR)	MPa	≥ 12
Density (Modified Proctor)	% of maximum dry density	≥ 97
Collapse	%	< 0.5
Free swelling	%	< 1.5
Organic matter	% of mass	< 1
Soluble sulphate	% of mass	< 0.7
Minimum workability time	hour	> 3

This job mix formula was obtained in laboratory mixing different percentages of WPFA (2.5, 3.0 and 3.5%) and compacting the mix at 97% of the reference density in order to determine the CBR value. The results indicated that 3% of WPFA was enough to achieve the minimum CBR. Moreover, the other parameters indicated in Table 1 were also fulfilled.

The demonstration consisted in 1 km long field trial of an unpaved road, divided in two sections: a section 900 m long using the WPFA and a section 100 m long using lime as control. As shown in Figure 2, on the paperChain solution, a 25 cm thick layer of a silty clay stabilized with 3 % of WPFA was used as an improved subgrade. On top of this layer, a protective granular layer of 10-12 cm thickness was placed. This field trial was initially used during the dosage and laboratory study to evaluate the quality of the WPFA and to check the technical performance of this material as an alternative hydraulic road binder for this specific use.

Figure 2: *Distribution of layers in demonstrator service road*

The construction involved the following stages:

- Soil mixing: spreading of 3% of WPFA on top of the newly exposed soil (clays and marls). Blending with the stabiliser machine of the first 25 cm of soil with the WPFA and water addition until reaching the optimum moisture content.
- Initial compaction: compaction of the resulting layer.
- Levelling: surface refining with a grader.
- Final compaction: re-compaction.
- Surface protection: spreading and compaction of a new granular layer (10-12 cm thick) on top of the stabilized layer.

2.2. Sustainability assessment

The Brundtland Commission defined sustainable development as the *development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (WCED, UN, 1987). Commonly, this has been broken into three objectives known as the triple bottom line of sustainability: enhancing social aspects, increasing economic benefits and decreasing environmental negative impacts.

Considering this, sustainability can be defined as a characteristic of a system (Bryce, J. et al., 2017) (in this case a system will be a product or a service) that reflects the behaviour of that system regarding the three dimensions of sustainable development. Sustainability is not an absolute property but a relative one as it needs to be compared in order to evaluate it. A system cannot be declared as sustainable by itself, but it can be declared as more (or less) sustainable that other.

Even so, it is difficult to make such a statement as it is hard to compare between the three dimensions of sustainability. From a more rigorous point of view, the comparison of sustainability between two or more systems must be done comparing results dimension by dimension and impact by impact.

In any case, as this approach many times is impractical as no final conclusions can be extracted, another more practical approach can be applied which consists in applying a weighting method which assigns different weights to each indicator and to each dimension of sustainability so, at the end, a sustainability index is obtained for each system which eases comparison between them.

2.2.1 To evaluate each of the dimensions of sustainability, life cycle assessment has shown its potential and

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adequacy. When applying life cycle perspective to the evaluation of a system (a product or a service), the evaluator considers not only the system itself but also all the systems that are related with it in its whole life cycle, upstream and downstream, i.e., from the extraction of the raw materials that are part of the system to its end of life. (e)-LCA

Environmental life cycle assessment ((e)-LCA) is the methodology which permits to evaluate environmental impacts of a system (product or service) considering all stages of its life cycle. Nowadays, it can be considered as a robust and reliable methodology which can be applied with the help of standalone software programs and making use of many databases. Likewise, the methodology has been standardized and two are the main methodology references: ISO 14040:2006 (ISO/TC 207, 2006a) together with ISO 14044:2006 (ISO/TC 207, 2006b) and the ILCD handbook (European Commission - Joint Research Centre - Institute for Environment and Sustainability, 2010).

In this case, ISO 14040:2006 and ISO 14044:2006 have been applied as reference methodology.

The environmental impact categories assessed have been those defined in the product category rules of the EPD international system for highways, streets and roads (except elevated highways) (International EPD System, 2018), which are the following:

- GWP100: Emission of greenhouse gases (expressed as the sum of global warming potential, GWP, 100 years, in carbon dioxide equivalents, CO2 eq.),
- AP: Emission of acidifying gases (expressed as the sum of acidifying potential in sulphur dioxide equivalents, SO2 eq.),
- EP: Emission of substances to water contributing to oxygen depletion, “eutrophication” (expressed as phosphate equivalents, PO43-eq.),
- POFP: Emission of gases that contribute to the creation of ground-level ozone, “photochemical oxygen creation potential” (expressed as the sum of ozone-creating potential, in ethylene equivalents, C2H4 eq.)
- ODP: Emission of ozone-depleting gases (expressed as the depletion potential of the stratospheric ozone layer, ODP kg CFC 11 equiv)
- ADP: Depletion of abiotic resources-elements (expressed as Abiotic depletion potential (ADP-elements) for non-fossil resources, kg Sb equiv)
- ADP-FF: Depletion of abiotic resources-fossil fuels (expressed as Abiotic depletion potential (ADP- fossil fuels) for fossil resources, MJ, net calorific value)

  The characterization models and factors used to calculate each environmental impact category were those developed in the CML-IA (baseline) methodology released in 2013. Likewise, another two additional environmental impacts have been assessed:

- CED: Cumulative Energy Demand (MJ)
- WU: Water resources used (m3)

2.2.2. LCC

Life Cycle Costing assessment is the methodology that permits to evaluate the costs of each solution during its life cycle. In this case, the methodology applied as reference was the ISO 15686-5:2017 (ISO/TC 59, 2017).

To perform this assessment the data collected corresponded to:

- materials acquisition cost,
- rental of equipment used which included the manpower,
- cost of transport of materials and
- cost of energy consumed, in this case the cost of the fuel consumed by the equipment used in the construction works.

2.2.3. s-LCA

Social Life Cycle Assessment is the methodology that permits to evaluate the social impacts and benefits of a system during its life cycle. For this study, the methodology applied as reference was that described in the Guidelines for Social Life Cycle Assessment of Products (Andrews, E. S. et al., 2009).

To perform this assessment, apart from the information collected for the (e)-LCA and the LCC, specific information about the manpower and operation time was gathered.

2.2.4. LCSA

Life Cycle Sustainability Assessment is the methodology that permits to evaluate the three dimensions of sustainability in a coordinated way which will *facilitate to organize environmental, economic and social information and data in a structured form, to assess the trade-offs between the three sustainability pillars, life cycle stages and impacts, products and generations by providing a more comprehensive picture of the positive and negative impacts along the product life cycle and to help decision-makers choose sustainable technologies and products* (Ciroth, A. et al., 2011). For this study, the guidelines defined in the document *Towards a Life Cycle Sustainability Assessment: Making informed choices on products* (Ciroth, A. et al., 2011) have been considered.

2.2.5. Functional unit and limits of the system

The functional unit was 1 m^3 of the stabilised layer. Considering that WPFA section was 900 m long, 5 m wide and the stabilised layer was 25 cm thick, a total of 1125 m^3 of stabilised layer with WPFA have been constructed. On the other hand, the conventional stabilised layer built as control reference was 100 m long, 5 m wide and the stabilised layer was 25 cm thick, so that implying 125 m^3 of conventional stabilised soil.

Figure 3 shows the limits of the assessed system, where all processes involved during the construction stage have been included. Likewise, a use stage was modelled and included within the limits of the system. On the contrary, the end of life stage for both, the WPFA stabilised layer and the lime stabilised layer, has not been included within the limits of the system as there is no difference for this stage between both solutions. For the same reason, the circulation of vehicles during the use stage of the road was discarded too in the assessment.

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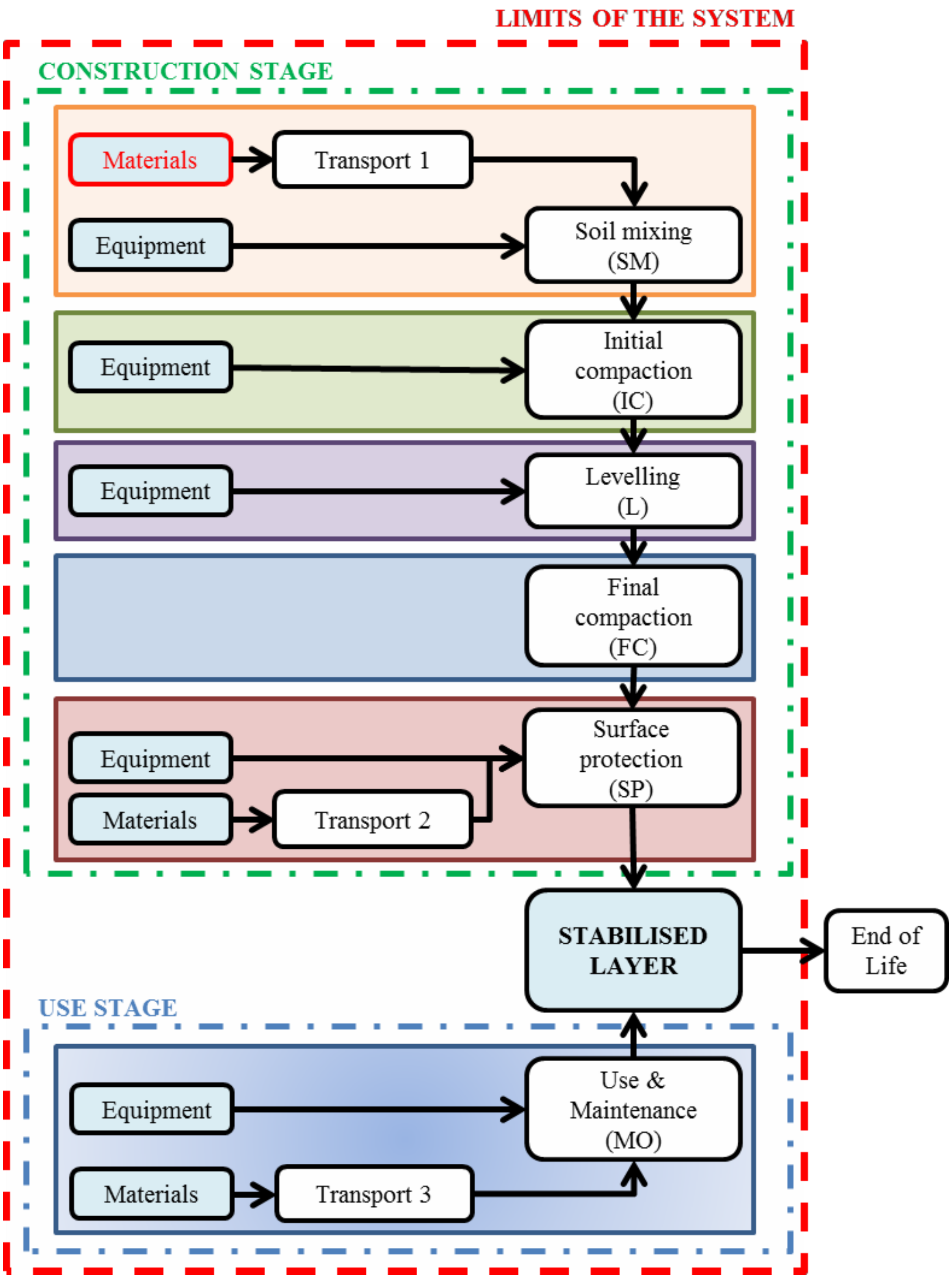

Figure 3. *Processes, stages and limits of the product system*

2.2.6. Allocation procedures

A cut-off system model has been applied and consequently, recyclable materials are available burden-free to recycling processes, and secondary (recycled) materials bear only the impacts of the recycling processes. No other allocation procedure was used in this study.

2.2.7. Transport distances

Logistics of the materials during the construction and maintenance works in this kind of infrastructure is key, not only from the economic point of view, but also from the environmental and social perspectives. According to this, transportation of the WPFA and lime used in the pilot were specifically evaluated for the life cycle assessments made. The distance from the provider of these materials to the placement where the pilot was built was 90 km for the WPFA and 350 km for the Lime. A 32 tonnes lorry Euro 4 class made the transport.

Anyway, due to the relevance of this factor in the assessments, the relation between these two distances was calculated determining the distance at which the construction was sustainable regarding each of the impacts.

3. Results and Discussion

3.1. Construction of the road

Construction was done following standard procedures for this kind of works. There were no changes in terms of machinery, protocols or personnel allowing an appropriate comparison when changing from lime to WPFA.

Different Key Performance Indicators were measured in the pilot construction to assess any change in productivity due to the binder replacement. A slight loss of productivity was observed when using WPFA due to a lack of expertise handling this material and at a lesser extent, the slightly lower density of WPFA with respect to lime.

3.2. Sustainability assessment

As indicated before, the sustainability assessment was made according to the LCSA methodology described in the guide *Towards a Life Cycle Sustainability Assessment* and therefore the results shown following correspond to the (e)-LCA, LCC and s-LCA conducted in a coordinated way as describe in these guidelines.

3.2.1. Environmental results

The (e)-LCA was conducted with the help of the software tool Simapro 8.5.2.0. Both systems have been modelled making use of the data collected by the responsible of the construction works of both sections, the section in which the WPFA have used and the test section using lime. When necessary, processes and products used in the construction works were modelled making use of the Ecoinvent 3.4 database.

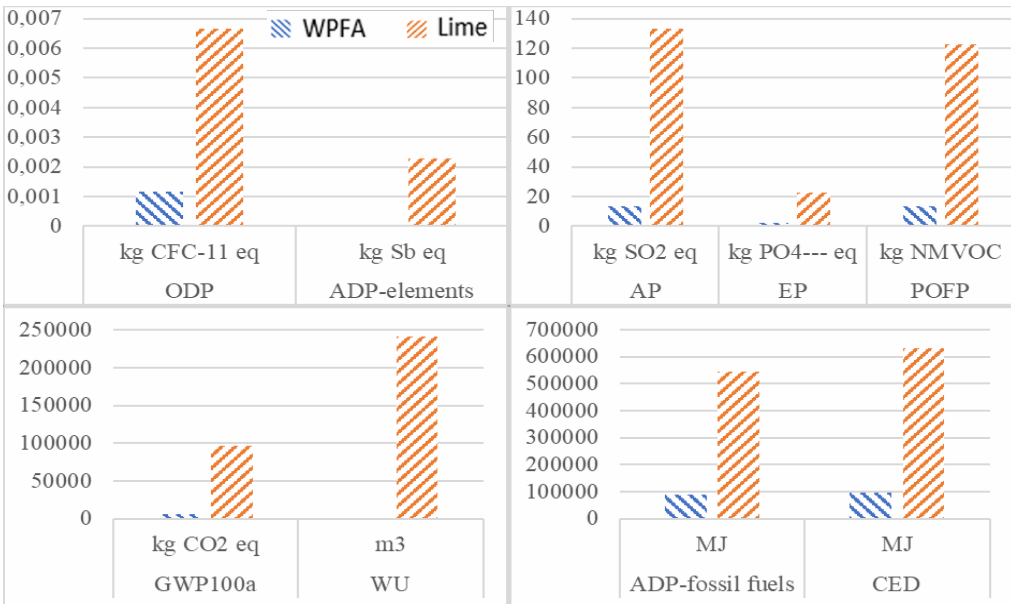

Figure 4. *Global results of the (e)-LCA*

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The global results for each of the nine environmental impact categories analysed are shown in Figure 4. As it can be seen, for all impact categories, the conventional solution generates higher environmental impacts than the solution using the WPFA.

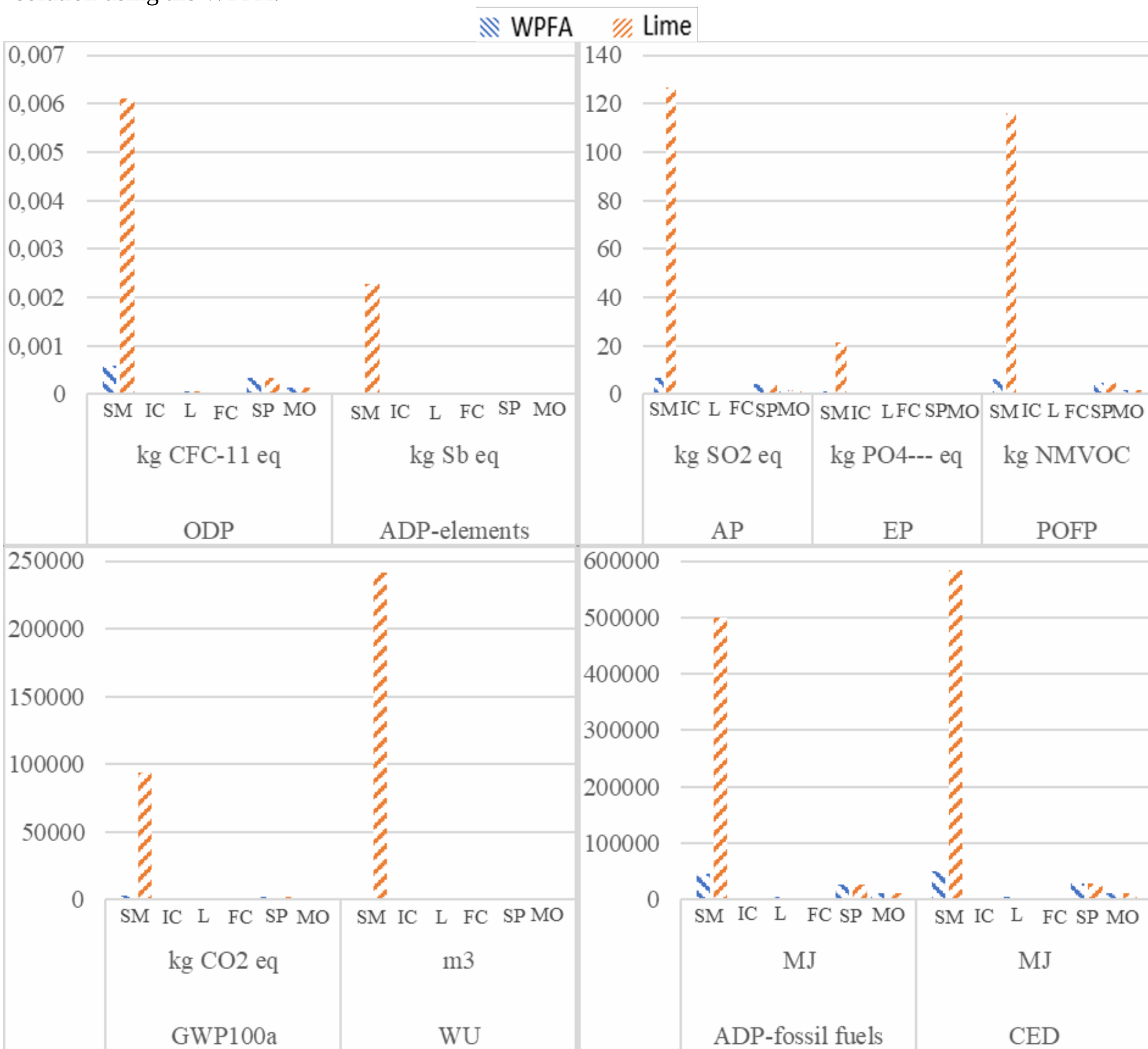

Figure 5. *Environmental impacts by process*

When analysing these results more thoroughly, evaluating each of the processes involved in the construction and use stages of the lifecycle of the road, see Figure 5, it is clear that the process with the highest repercussion for all environmental impact categories is the Soil Mixing. This is because most of the materials involved in the road construction are added and blended in this process and, consequently, much of the energy consumption in the life cycle of the road takes place at this moment.

This also explains why the conventional road construction has higher environmental impacts than the WPFA road. The conventional road construction consumes lime, which is a natural resource (CaCO3) extracted directly from nature and which further processing (decarbonisation by heating) entails a lot of energy consumption. Meanwhile, the construction of the WPFA stretch implies full substitution of lime by WPFA, preventing WPFA from being landfilled, consequently, no environmental impacts have been allocated to it.

However, certain loss of efficiency and productivity was observed during the application of the WPFA in comparison with the control stretch with lime due to the lack of expertise handling this material. This side effect has implied more working time and consequently, more energy consumption of the equipment with respect to the conventional road construction when applying lime. This is expected to be reduced with training to workers using this kind of materials and more experience working with them.

3.2.2. Economic results

The LCC was deployed using an Excel spreadsheet. All the data used was provided by the company in charge of the construction works of both sections of the road. Additionally, some parameters have to be defined to perform the assessment as shown in Table 2 and Table 3.

Table 2. *LCC general parameters definition.*

Energy cost	
Electricity cost (€/kWh)	0,0
Diesel fuel cost (€/l)	0,6
Equipment and machines	
Life time expectancy (y)	4
Depreciation period	3
Payback period (y)	
Working conditions	
Working days per year	22
Hours/working shift	170
Number of working shifts	
Man cost/hour (€/h)	1
Working time per day (h)	
External transport	
Transport cost in lorry (€/km)	1,1
Maximum load capacity (t)	3
Maintenance operations	
Frequency (years)	
Number of operations	

Table 3. *Material parameters definition*

	WPFA	Lime
Material price (€/ton)	- €	115,42 €
Distance final destination (km)	90	350

The results obtained have shown that the WPFA road solution is more economically advantageous than the lime

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road solution, as their cost have been 15,59 €/m^3 and 22,54 €/m^3 respectively.

This is due, mainly, to the cost of the lime and, to a lesser extent, to its transport cost as can be seen in Figure 6.

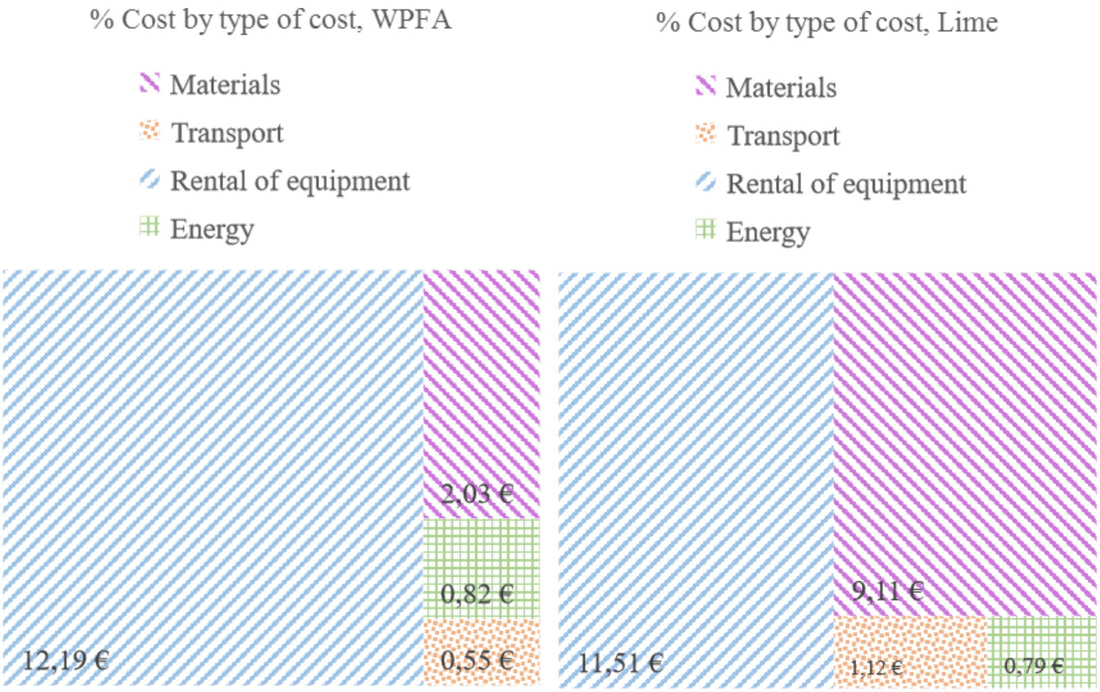

Figure 6. *LCC results by type of cost*

Likewise, for both solutions, the soil mixing and surface protection processes of the construction stage involve the highest costs in the life cycle as shown in Figure 7. The costs generated during the maintenance operations in the use stage are significant although they only represent 11% (WPFA road solution) and 7% (lime road solution) of the total costs.

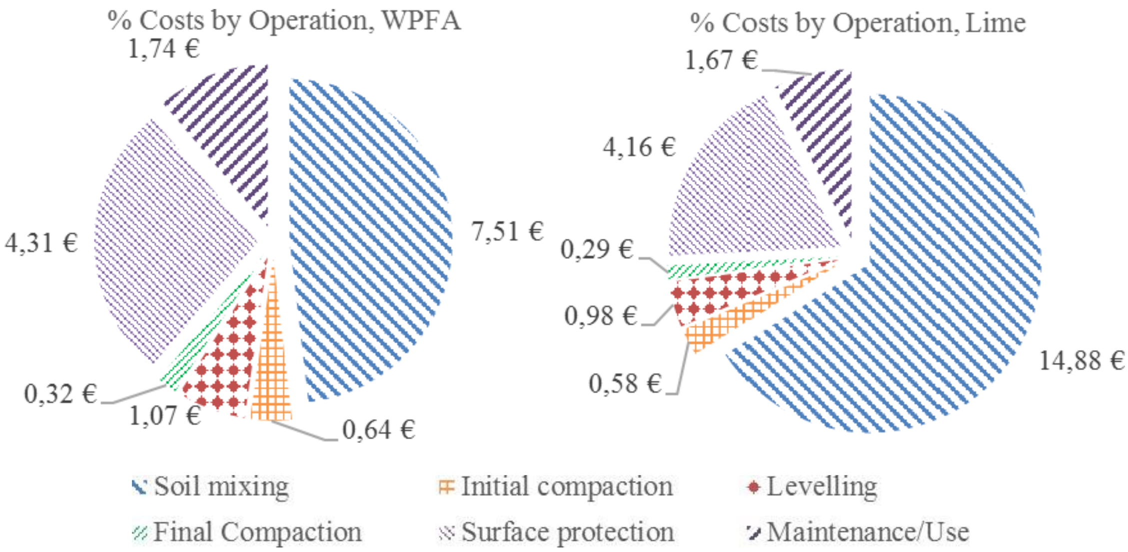

Figure 7. *LCC results per process of the life cycle*

3.2.3. Social results

The s-LCA was made using the software tool OpenLCA and the social impacts database PSILCA version 2.0. Both solutions were modelled using the data provided by the company responsible of the construction works. It has been considered 5 stakeholder categories: consumers, local communities, society, value chain actors and workers, and for each of these, the impact and benefit social indicators defined in the guidelines of the s-LCA

methodology and the methodological sheets for subcategories in social life cycle assessment (Andrews, E. S. et al., 2009, Benoît Norris, C. et al., 2013) have been calculated.

The results shown in Table 4 demonstrate that for all impact and benefit social indicators the performance of the WPFA road solution is better than that of the lime road solution according to the conditions in which the construction works have been performed.

Table 4. *Results of the s-LCA*

CONSUMERS				
Subcategory	**Impact category**	**WPFA**	**Lime**	**Unit**
Transparency	Presence of business practices deceptive or unfair to consumers	0,0010608	0,0016240	CONS med risk hours
LOCAL COMUNITIES				
Subcategory	**Impact category**	**WPFA**	**Lime**	**Unit**
Access to material resources	Biomass consumption	0,1156140	0,1683770	BM med risk hours
	Certified environmental management system	0,4750060	5,6550400	CMS med risk hours
	Fossil fuel consumption	0,0010519	0,0015385	FF med risk hours
	Industrial water depletion	0,1256650	0,2641320	WU med risk hours
	Minerals consumption	0,1062460	0,1554710	MC med risk hours
Local employment	Unemployment	10,5087000	15,2907000	U med risk hours
Migration	International migrant stock	1,0518600	1,5384700	IMS med risk hours
	International migrant workers (in the sector/ site)	0,1326630	0,2216590	IMW med risk hours
	Net migration	0,1050870	0,1529070	NM med risk hours
Respect of indigenous rights	Indigenous rights	0,0000000	0,0000000	IR med risk hours
Safe and healthy living conditions	Contribution to environmental load	0,4544620	28,8704000	CS med risk hours
	Drinking water coverage	0,0010519	0,0015385	DW med risk hours
	Pollution	0,0105186	0,0153847	P med risk hours
	Sanitation coverage	0,0110214	0,0965235	SC med risk hours
SOCIETY				
Subcategory	**Impact category**	**WPFA**	**Lime**	**Unit**
Contribution to economic development	Contribution to economic development	-0,1023380	-0,1461160	CE med risk hours
	Education	1,0509600	1,5299200	E med risk hours
	Illiteracy, female	0,0105096	0,0152992	I med risk hours
	Illiteracy, male	0,0105096	0,0152992	I med risk hours

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	Illiteracy, total	0,0105096	0,0152992	I med risk hours
	Youth illiteracy, female	0,0010519	0,0015385	YI med risk hours
	Youth illiteracy, male	0,0010519	0,0015385	YI med risk hours
	Youth illiteracy, total	0,0010519	0,0015385	YI med risk hours
Health and Safety (Society)	Health expenditure	0,2218520	0,3237630	HE med risk hours
	Life expectancy at birth	0,0000000	0,0000000	LE med risk hours
VALUE CHAIN ACTORS				
Subcategory	**Impact category**	**WPFA**	**Lime**	**Unit**
Corruption	Active involvement of enterprises in corruption and bribery	0,4173070	0,9938220	AI med risk hours
	Public sector corruption	1,0518600	1,5384700	C med risk hours
Fair competition	Anti-competitive behaviour or violation of anti-trust and monopoly legislation	0,0204791	0,1102840	AC med risk hours
Promoting social responsibility	Social responsibility along the supply chain	1,0546800	1,6180300	SR med risk hours
WORKERS				
Subcategory	**Impact category**	**WPFA**	**Lime**	**Unit**
Child labour	Child Labour, female	0,0000000	0,0000000	CL med risk hours
	Child Labour, male	0,0000000	0,0000000	CL med risk hours
	Child Labour, total	0,0000000	0,0000000	CL med risk hours
Discrimination	Gender wage gap	1,0207300	1,4553300	GW med risk hours
	Men in the sectoral labour force	0,0013356	0,0023021	M med risk hours
	Women in the sectoral labour force	0,1150560	0,2478920	W med risk hours
Fair Salary	Fair Salary	0,1169320	0,1705080	FS med risk hours
Forced Labour	Frequency of forced labour	0,0010519	0,0015385	FL med risk hours
	Goods produced by forced labour	0,0105186	0,0153847	GFL med risk hours
	Trafficking in persons	0,0010519	0,0015385	TP med risk hours
Health and Safety (Workers)	DALYs due to indoor and outdoor air and water pollution	0,0010519	0,0015385	DALY med risk hours
	Fatal accidents	0,0023227	0,0117065	FA med risk hours
	Non-fatal accidents	10,5186000	15,3847000	NFA med risk hours
	Safety measures	1,1124700	1,5892700	SM med risk hours
	Workers affected by natural disasters	0,0011506	0,0024789	ND med risk hours
Social benefits, legal issues	Association and bargaining rights	0,0000100	0,0000950	ACB med risk hours
	Social security expenditures	0,0105186	0,0153847	SS med risk hours

	Trade unionism	10,5096000	15,2992000	TU med risk hours
	Violations of employment laws and regulations	0,1335600	0,2302090	VL med risk hours
Working time	Weekly hours of work per employee	0,1050960	0,1529920	WH med risk hours

3.2.4. Transport distances of sustainability

According to these results, it can be concluded that the construction of a rural service road with the characteristics abovementioned and constructed as described, using WPFA instead of lime is more sustainable, while the technical properties of the service road remain equivalent.

These results depend heavily upon the materials logistics and especially in the WPFA and lime transportation. For this reason, the maximum distance at which the WPFA could be provided to the site regarding that of the lime for each of the analysed impact categories has been calculated according to the following formula:

$$d_W = d_L + R$$

where:

d_W is the distance from the facilities of the provider of WPFA to the site where the road is constructed,

d_L is the distance from the facilities of the provider of WPFA to the site where the road is constructed,

X is the difference between d_W and d_L.

The results obtained are shown in Table 5.

Table 5. *Distances to provider at which WPFA road solution remains more sustainable than the Lime road solution for each impact category*

Impact category	**X**	**dL**	**dW**
Value Chain Actors	568	350	918
Photochemical Oxidant Formation Potential	198	350	2332
Cost	198	350	2336
Society	233	350	2683
Workers	256	350	2915
Ozone Depletion Potential	268	350	3033
Eutrophication Potential	269	350	3045
Abiotic Depletion Potential Fossil Fuels	287	350	3220
Consumers	300	350	3352
Acidification Potential	313	350	3488
Cummulative Energy Demand	319	350	3540
Global Warming Potential	879	350	9148
Local Communities	986	350	10210
Abiotic Depletion Potential Elements	9888	350	99238
Water Use	15018	350	150532

This means that, for a specific impact category, whenever X is below the distance indicated in the Table 5, the use of WPFA instead of lime will be more appropriate regarding that impact category. Therefore, whenever the WPFA provider is 568 km or less farther away from the construction site than the lime provider then, the

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construction of the road using WPFA will be more sustainable than using lime. If X is over 568 km, a more thorough evaluation of the results has to be done as the sustainability will depend on the interest of the stakeholders involved in the construction of the road, whom will have to define priorities between impact categories.

4. Conclusions

In the last years, circular economy has become one of the main strategies of the European Commission to face the environmental, social and economic problems related with the management of material resources in the European Union.

Consequently, many new products and business models are being developed which must demonstrate their technical and economic feasibility but also, they must demonstrate that they will improve the sustainability of the current products and business models.

At this point, life cycle assessment has been revealed as a powerful method, which traditionally has offered the opportunity to assess environmental ((e)-LCA) and economic (LCC) aspects of a system (product or service) but which has evolved to assess social aspects (s-LCA) and finally the sustainability (LCSA) of a system. Some of the main strengths of life cycle assessment are,

- allows practitioners to have a thorough control of any impact trade-offs between different stages of the life cycle, between the three pillars of sustainability or between impact categories or products,
- supports decision-makers to adopt more sustainable solutions,
- helps organizations to implement and achieve SCPs.

On the other hand, one of the biggest barriers for using this method is the big amount of data needed to get accurate results, although this problem has been minimised in the last years with the development of new, updated and more extensive databases, mainly to assess environmental and social impacts.

Finally, the LCSA methodology has offer a reference framework to assess sustainability of a system in its life cycle making use of the (e)-LCA, LCC and s-LCA in a coordinated way, i.e., defining a common goal and scope for the three individual assessments which facilitates the interpretation of results and the decision making.

Regarding the sustainability of a service road consisting of a stabilised layer using WPFA compared with a conventional service road using lime, results have demonstrated that, in the conditions in which the demonstrator and the control roads have been built, the WPFA- stabilised layer is more sustainable than the lime-stabilised layer as environmental, economic and social impacts are lower.

This is mainly because of the environmental and social impacts associated with the lime production, while the WPFA, as it was diverted from being landfilled, has been assigned no impact. Likewise, WPFA has no cost in this trial while lime has been assigned a price of 115,42 € per tonne.

Regarding the conditions at which WPFA stabilised-layer is more sustainable than lime stabilised-layer, it has been stated that the distance to the construction site from the WPFA and the lime providers is key. At this regard, whenever the difference between the distance of the WPFA provider to the construction site and the distance of the lime provider to the construction site is lower than 568 km, the WPFA stabilised-layer will remain more sustainable than the lime stabilised-layer. If this difference exceeds 568 km, then a prioritisation of all impact categories for the three dimensions of sustainability will be needed to assess sustainability. For the definition of this prioritisation, the participation of all stakeholders involved would be advisable.

Acknowledgements

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Analyzing the Decision to Invest in Recycling: the Role of Demand Uncertainty and the Rebound Effect.

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Abstract

The reduction in the consumption of virgin material is considered one of the most important environmental benefits of the transition towards a circular economy. However, as positive externalities are not internalized and investors face demand uncertainty, private investment in the circular economy is lagging behind. This study analyses a monopolistic firm with the option to invest in a recycling facility, taking into account demand uncertainty. The analysis internalizes the environmental externalities of recycling, taking into account the rebound effect. Such rebound effects occur whenever recycled material does not fully displaces virgin material. On the one hand, the objective is to analyze the impact of environmental externalities of recycling on the decision to invest in a recycling facility. On the other hand, the discrepancy of investment thresholds between profit maximization and welfare maximization are calculated and analyzed. The theoretical framework is applied to a case study in the plastics waste industry. In order to incorporate demand uncertainty and environmental externalities, the real option theory is used. An existing real option model is extended by incorporating the environmental externalities of recycling. Using this extended model, the optimal investment thresholds *i.e.* the optimal investment trigger and the optimal investment capacity are calculated. We find that internalizing positive environmental externalities lowers the optimal investment threshold as well as the optimal investment capacity. The optimal capacity in which a firm invests in, increases in case of welfare maximization.

Keywords: Circular Economy, Real Option Analysis, Rebound Effect, Recycling, Plastics

* Corresponding author

1. Introduction

This study will provide a reasoned framework in which the motivation for the transition towards circularity is nuanced by market conditions and environmental science-based insights. The transition towards a circular economy (CE) has gained a lot of positive attention over the past decade. This positive image is supported by a prevailing paradigm that every transition towards circularity lowers environmental impacts drastically (Zink & Geyer, 2017). In this study, a CE is defined as a holistic economic system, taking into account environmental, economic, and social sustainability. This economic system is inspired by the idea of *reduce*, *reuse*, and *recycle* (3R) (Kirchherr, Reike, & Hekkert, 2017). The current trend followed by governments and organizations can be characterized by the urge to make the transition towards circularity *e.g.* the European Commission has been highly active in publishing reports and adopting action plans concerning the CE (EC, 2013; EC, 2015; EC, 2018).

The introduced framework nuances this urge and focusses on a very specific case of circularity and its environmental impact. An investment analysis will be performed for a company with the option to invest in a recycling facility, while taking into account *demand uncertainty* and the potential *rebound effect* of positive environmental externalities. A case study focusing on an investment option in a plastic recycling facility will be considered. The outcome of the investment analysis provides results which are of great value to the policy making world. A deeper understanding of incentives experienced by firms, allows tailored policy interventions. Demand uncertainty is considered in the investment analysis and can be observed *inter alia* on the market of recycled plastics. This market is in some countries of the world *e.g.* UK, driven by government regulations and objectives (Angus, Casado, & Fitzsimons, 2012). As a consequence, supply is typically inelastic and market dynamics mostly only influence the price. Demand uncertainty thus creates price volatility on the recycled plastics market (Stromberg, 2004). Price volatility on recycled material markets is often observed. An example besides the recycled plastics market would be the recycled paper market which is also typed by a high degree of volatility (Stromberg, 2004).

The innovative part of this paper is the inclusion of the rebound effect of positive environmental externalities in the investment analysis. A rebound effect occurs whenever recycled material does not fully substitute virgin material. In such cases the recycled material bears a negative environmental externality which was not present before recycling. This externality is typically not accounted for by firms in an investment analysis[1].Yet, the rebound effect is an important factor as it affects the welfare experienced by every citizen – externalities are borne by the aggregate of citizens.

The investment analysis is performed using a real option analysis (ROA) in order to study the optimal investment trigger to execute an investment option and determine the optimal capacity to invest in, given that demand uncertainty is present. The optimal investment trigger can for example be expressed in terms of market prices. A distinction will be made between the investment thresholds *i.e.* optimal trigger and optimal capacity, seen from a profit maximizing point of view and the investment thresholds, seen from a welfare maximizing

[1] The environmental externalities of producing goods, including recycled goods can be internalized via *e.g.* the European Union Emission Trading System (EU ETS). This system does not take the rebound effect into account.

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point of view.

Both analyses take the environmental externalities into account, including the rebound effect. Note that taking into account positive environmental externalities, including the rebound effect in a profit maximizing context is innovative. So far, rebound effects have been studied from a welfare maximizing point of view only. Measuring the discrepancy between thresholds of both points of view, and understanding the dynamics causing the divergence

allow proper policy interventions. Results show that the firm's optimal investment trigger as well as its optimal investment capacity is to the best of our knowledge, no study so far has discussed the dynamics of externalities and the rebound effect and its influence on investments in recycling facilities via a ROA. There are, however, papers discussing different aspects of our analysis. The idea of a rebound effect applied to a CE – circular economy rebound – has been researched and described by Zink & Geyer (2017). The comparison of investment thresholds resulting from profit and welfare maximization was shown in Huisman & Kort (2015). Nevertheless, there is a gap in the literature in terms of internalizing environmental externalities and the rebound effects in investment analyses

which are typed with demand uncertainty. Moreover, rebound effects applied to a situation typed with environmental

externalities, have not yet been studied from a profit maximizing point of view. . Though, in reality these rebound effects are present and experienced by both firms and society. The ROA has however been applied to a CE setting (Framstad & Strand, 2015); Traeger, 2014; Dellink & Finus, 2012)

The remainder of the paper will be organized as follows: section 2 will elaborate on the existing literature and the model. The first part 2.1, digs into the literature on the rebound effect. The second part 2.2, elaborates on the ROA and the changes we propose to the model initiated by Huisman & Kort (2015). Section 3 will show results obtained after applying the model to a case study in the plastic waste industry. Finally, section 4 will conclude and discuss our findings.

2. Literature and model

2.1 Rebound effect

The environmental benefits of a transition towards a CE[2] including reduced CO2 emissions, are often overestimated. The displacement rate of recycled material with respect to virgin material – that is the relative amount of virgin material substituted by recycled material – is rarely equal to one (Geyer, Kuczenski, Zink, & Henderson, 2016). The true aggregate environmental impact reduction is thus often limited as a result of the rebound effect (Zink & Geyer, 2017). This rebound effect results from the introduction of a new technology that lowers the cost of production and hence reduces sales prices. It was first introduced in the 19th century by theeconomist William Stanley Jevons (Jevons, 1865) in the context of coal mines in the UK. In his book "The Coal Question: Can Britain Survive?" he introduced a paradox: by technological improvements, resource efficiency per unit increases. As a result, the cost per unit will decrease, leading to increased purchasing power of consumers. This in turn will increase the consumers' consumption, leading to higher demand for resources.

2 In this study via recycling

It was only several years later that the idea of a rebound effect was further studied by Khazzoom (1980), and Brookes (1990). The rebound effect has been widely researched ever since, *e.g.* (Greening, Greene, & Di, 2000; Sorrell, 2009).

The effect can be divided into the direct – micro level – and indirect – macro level – rebound effect (Chan & Gillingham, 2014). The direct rebound effect is described by the price effect, *i.e.* income and substitution effect and

is situated on a single market (Binswanger, 2001; P. H. G. Berkhout, Muskens, & Velthuijsen, 2000). The indirect rebound effect is situated on an intermarket level, *e.g.* shifting consumer preferences, the recycled material will be

used in *new* applications for which the price of the original virgin material used to be too expensive. Although both rebound effects are most likely present after investing in a recycling facility, indirect rebound effects are extremely hard to measure (P. Berkhout, Muskens, & Velthuijsen, 1998). Therefore, this paper will only study direct rebound effects occurring after investing in a recycling facility.

In the broad sense of a CE, rebound effects are found (Amjadi, Lundgren, & Persson, 2018; N. Brooks et al., 2016), the production of a circular good is generally less energy-intensive than the production of virgin goods. This reduced production cost *i.e.* increased resource efficiency, generally offsets the "circularity cost" *e.g.* sorting cost, leading to lower sales prices. On the one hand, these lower sales prices result in higher purchasing power – income effect –, which in all likelihood leads to increased consumption (Varian, 1992). This income effect, which is part of the direct rebound effect (Sorrell & Dimitropoulos, 2008) is often discussed in literature on energy markets (Sorrell, 2009). This effect may also occur after recycling (Zink, Geyer, & Startz, 2018). On the other hand, these lower sales prices of the recycled good lead to a substitution effect with respect to the non-recycled alternative. The recycled material will be used in applications for which, in the past virgin material was used. As a result of both dynamics, the production of virgin material will not decrease in proportion to the production of recycled material. In other words, the displacement rate will not be a one-to-one ratio. In some extreme cases, where the actual resource savings are negative after recycling, the rebound effect leads to a situation called "backfire". However, this scenario is very rare (Borenstein et al., 2013) and this study will only focus on the situation where actual resource savings are still positive.

In the setup of this paper, the rebound effect is linked to the positive externalities of recycling. These positive externalities, including the rebound effect are internalized via a positive Pigouvian tax, imposed on recycling. Because a non-linear rebound effect is assumed, the positive tax will be assumed to decrease according to the positive externalities of recycling, which is decreasing as more material is recycled. Measuring the impact of the rebound effect on investment behavior is novel, most literature on rebound effects focusses on measuring the extent to which rebound effects are present. Implications of rebound effects from the investor's perspective have not yet been studied.

2.2 Real options analysis

The investment analysis performed in this study concerns a monopolistic firm with the option to invest in recycling. Competition is left outside the scope of the study, allowing to measure the impact of demand uncertainty, environmental externalities and the rebound effect on the individual firm's investment decision. The market organization of recycling markets is often typed by a few competitive players or even one

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monopolistic player. Therefore, the results of this study will serve as an intuitional understanding for existing dynamics. Further research could be built upon this study by introducing competition, for example. The investment analysis would then be focused on some very specific, perfect competitive recycling markets.

The thresholds calculated will depend on demand uncertainty and the internalization of environmental externalities including the rebound effect. The ROA is thus used to assess the influence of demand uncertainty and environmental externalities on investment behavior in recycling facilities. The base model for this study is the ROA monopoly model presented in Huisman & Kort (2015), where both the optimal investment trigger – that is the optimal point at which a firm should invest – and the optimal capacity for the investment are determined. The optimal investment trigger can be recalculated to the optimal price or the optimal timing. The model will be extended in order to internalize the environmental externalities including the rebound effect.

2.2.1 Profit maximization, taking into account environmental externalities

A monopolistic firm, experiencing a linear inverse demand function is considered (Dixit & Pindyck, 1994). The price ($P(t)$) is a time-dependent function of demand uncertainty and quantity produced:

$$P(t) = X(t)(1 - \eta Q(t)) \tag{1}$$

The parameter η is a constant. Q represents the firm's output of recycled material, equal to the market output because the firm is a monopolist. Demand uncertainty is modeled as an exogenous shock process denoted by X, which is assumed to follow a geometric Brownian motion:

$$dX(t) = \mu X(t)dt + \sigma X(t)d\omega(t) \tag{2}$$

This geometric Brownian motion has a drift rate which is represented by μ[3]. The increment of the Wiener process is equal to $d\omega(t)$, and σ represents a constant volatility. A discount rate r is assumed, which must be larger than the drift rate[4].

In order to calculate cash flows, the cost function experienced by the firm is defined. It is the cost function which extends the model of Huisman & Kort (2015), and enables an approach for investments within the CE. Instead of only taking the investment cost into account, this study includes the investment and production cost, as well as the

environmental externalities. It is important to mention that all costs are expressed per unit and, except for the investment cost, perpetually summed. We follow the original paper in assuming production is up to capacity. The production cost, which is assumed to be linear, is described by (3):

[3] A growing market is assumed, therefore, μ is assumed to be positive. Because the market is growing, waiting can yield higher returns.
[4] Otherwise the investment will be delayed indefinitely as the option value will always be greater than the investment value if discounted with $r < \mu$. This is true because the integral of the discounted cash flows could be made indefinitely larger if $r < \mu$

$$\sum_{t=T}^{\infty} c = C \tag{3}$$

Capital C is thus equal to the total production costs per unit. Later on, this cost will be discounted. The same summation is performed for the environmental externalities of recycling. However, this is executed in two steps. The first step is to take into account what is called 'the gross environmental gains of recycling'. Recycling material is generally less energy intensive than producing virgin material. It is assumed that energy savings go together with lower environmental impact. The environmental impact of virgin material production (env_{virgin}) is thus assumed to be higher than the environmental impact of recycling material ($env_{recycled}$). The gross environmental gains of recycling are thus positive and equal to ($env_{virgin} - env_{recycled}$), the difference is represented with the parameter env.

.

$$\sum_{t=T}^{\infty} env = E \tag{4}$$

Parameter E is thus equal to the total gross environmental gains of recycling (4). Again, discounting will be performed at a later stage. The perpetually summed cost function experienced by a firm when linear externalities are fully internalized at the firm's level equals (5):

$$cost\ function = (i + C - E)Q \tag{5}$$

However, as mentioned above, a rebound effect occurs after recycling material. The second step is to take this rebound effect into account. After correcting for the rebound effect, we obtain what is called 'the net environmental gains of recycling'. This rebound effect is corrected for in a non-linear way. The marginal benefit of recycling to the environment is diminishing. Following standard economic theory on utility maximization, diminishing returns are a well-known phenomenon (Varian, 1992). This means that the displacement rate of recycled material with respect to virgin material is decreasing as more material is recycled. As a consequence, the aggregate consumption of virgin and recycled material together will grow disproportionate compared to the amount of recycled material. This model will only consider the direct – within one sector – rebound effect. Substitution between different materials *e.g.* recycled plastics substituting wood, is not taken into account here.

The extent to which aggregate consumption grows after recycling, can be measured using the displacement rate. The displacement rate, describing the substitution rate, is dependent on the quantity recycled. A higher marginal displacement rate will be experienced when the recycled quantity is low, and vice versa. Equation (6) shows the cost function taking into account the investment cost, production cost, environmental externalities including the rebound effect (QZ). Parameter Z is a constant ($0 \leq Z < 1$) and calibrates the rebound effect. The aggregate cost function generates a quadratic relation, $Q2(t)$. This relation follows a path similar to the rebound effect's path, but amply overshoots the experienced rebound effect. For this reason, a constant Z is multiplied with $Q2(t)$, calibrating the relation to the experienced rebound effect. The multiplication $Q2(t)Z$ thus mimics

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the rebound effect parameter.

$$cost\ function = (i + C - E + QZ)Q \quad (6)$$

The incoming cash flows, when positive environmental externalities and the possible rebound effect are internalized therefore equal the price minus costs, multiplied by the quantity produced/sold (7):

$$CF(t) = Q(t)X(t)\big(1 - \eta Q(t)\big) - Q(t)C + Q(t)E - Q^2(t)Z \quad (7)$$

The objective of the ROA is to define an optimal point to invest in recycling, and an optimal recycling capacity Q^*, both corresponding to a value X, X^*. Using a ROA instead of a net present value (NPV) analysis, gives an investment incentive to a firm when the project is deep enough into-the-money, instead of giving an investment incentive when the project has a positive return. The value of the investment $V(X)$ equals the expected value of the discounted cash flows and investment cost at a time T[5] corresponding with a certain value X (8):

$$V(X) = \max_{T\geq 0, Q\geq 0} E\left(\begin{matrix} \int_{t=T}^{\infty} QX(t)(1-\eta Q)e^{(-rt)}\,dt - \int_{t=T}^{\infty}(QC)e^{(-rt)}\,dt + \int_{t=T}^{\infty}(QE)e^{(-rt)}\,dt - \\ \int_{t=T}^{\infty}(Q^2Z)e^{(-rt)}\,dt - iQe^{(-rT)} \end{matrix} \middle| X(0) = X \right) \quad (8)$$

The value of the geometric Brownian motion (X) at which a firm is indifferent to invest is denoted by X^*. Whenever $X < X^*$, the value of waiting is greater than the value of investing, and firms will postpone investments. If $X \geq X^*$, firms will execute their investment option. The optimal capacity a firm should invest in, is also determined by the value of X, hence $Q^*(X^*)$.

Firstly, the optimal capacity Q^* is determined. The appendix (proposition 1) elaborates on the calculation of the expected value at the moment of the investment, given a current level for X and a capacity Q. After maximization with respect to Q, expression (9) is obtained. This expression defines Q^* which holds for any given level of X:

$$Q^*(X) = \frac{1}{2}\left(\frac{-i(r-\mu)+X-C+E}{X\eta+Z}\right) \quad (9)$$

Secondly, the optimal investment trigger X^* is calculated following the theory initiated by Huisman & Kort (2015). The general expression for calculating the value of the option to invest, denoted by F is equal to:

[5] Time T corresponds to the moment in time when the investment is made and can be recalculated to an optimal Price P. This study will express results in terms of X and P

$$F(X) = AX^{\beta} \tag{10}$$

Both A and β are calculated in the appendix (proposition 2). Finding the optimal investment trigger X^* is performed by calculating the value-matching and smooth-pasting conditions:

$$F(X^*) = V(X^*, Q) \tag{11}$$

$$\frac{\partial F(X)}{\partial X}\Big|_{X=X^*} = \frac{\partial V(X,Q)}{\partial X}\Big|_{X=X^*} \tag{12}$$

The optimal investment trigger, corresponding to any value of Q is defined by (13):

$$X^*(Q) = \frac{\beta}{\beta-1} \cdot \frac{(i(r-\mu)+C-E+ZQ)}{1-\eta Q} \tag{13}$$

The optimal quantity Q^*, corresponding to the optimal investment trigger X^* equals (14), and is obtained after substituting (13) in (9):

$$Q^*(X^*) = \frac{1}{2}\left(\frac{-i(r-\mu)+\left(\frac{\beta}{\beta-1} \cdot \frac{(i(r-\mu)+C-E+ZQ)}{1-\eta Q}\right)-C+E}{\left(\frac{\beta}{\beta-1} \cdot \frac{(i(r-\mu)+C-E+ZQ)}{1-\eta Q}\right)\eta-Z}\right) \tag{14}$$

The value of the investments is determined by a system of equations depending on the value of the geometric Brownian motion

$$V(X) = \begin{cases} AX^{\beta} & if\ X < X^* \\ \frac{XQ^*(1-\eta Q^*)-CQ^*+EQ^*-ZQ^{*2}}{r-\mu} - iQ^* & if\ X \geq X^* \end{cases} \tag{15}$$

The system reveals that the investment will be postponed whenever $X < X^*$, the value of waiting is then equal to AX^{β}. If $X \geq X^*$, the value of the investment is equal to the NPV,

$$\frac{XQ^*(1-\eta Q^*)-CQ^*+EQ^*-ZQ^{*2}}{r-\mu} - iQ^*$$

The tangent point of these two equations corresponds to the value of X^*.

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2.2.2 Welfare maximization

Section 2.2.1 aims to enhance social welfare; environmental externalities of recycling are included in the market mechanism. However, only producer surplus is maximized, leading to an outcome which is not desired by the community. Welfare maximization aims to maximize social welfare by also taking the consumer surplus into account. Note that the setting remains constant; the firm with the investment option is a monopolistic firm. Producer surplus (PS) was maximized in the appendix (proposition 3), and is equal to the value of the investment $V(X, Q) = PS(X, Q)$ (16).

$$PS(X,Q) = \frac{XQ(1-\eta Q)-CQ+EQ-ZQ^2}{r-\mu} - iQ \qquad (16)$$

The consumer surplus (CS) can easily be determined by calculating the integral of the demand function. The appendix elaborates on this calculation. Consumer surplus equals equation (17):

$$CS(X,Q) = \frac{XQ^2\eta}{2(r-\mu)} \qquad (17)$$

The expected total surplus is the sum of both consumer and producer surplus.

$$TS(X,Q) = \frac{XQ(2-\eta Q)-2Q(C+E-ZQ)}{2(r-\mu)} - iQ \qquad (18)$$

Calculating the investment thresholds under welfare maximization leads to an optimal investment timing equal to equation (13) and an investment capacity which is twice the size of the optimal capacity under profit maximization. Our calculations can be found in the appendix (proposition 4).

3. Results

3.1 Case study

Results are based on a case study in the plastics recycling sector. The case study focusses on private investment lagging behind in the plastics recycling industry in Europe for certain types of plastics. Given the current focus of the EU on plastics (EC, 2018), more investments are desired. These extra investments would enable the EU's market to exploit the full potential locked inside the plastic waste streams. Next to valorizing the resources in these waste streams, recycling would also lower the overall impact of plastics on the environment. Recycled plastics typically have a lower environmental impact. However, the actual – net – environmental impact reduction will be dependent on the displacement rate, as well as the environmental efficiency of recycling. Still, in most cases, the corrected impact reduction will be positive[6] - actual avoided impact. The avoided impact is in fact a function of the quantity recycled, the absolute environmental impact difference between producing virgin material compared with recycled material, and the displacement rate which is partially explained by the recycled quantity. The function results in a threshold value, determining the point

[6] No backfire

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where recycling does not bear any net environmental impact gains anymore. This threshold value is different for every case, the larger the absolute difference in environmental impact is between recycling and producing virgin material, the smaller the displacement rate can become and still generate positive net environmental gains.

As in the model, the case study will consider a monopolistic firm in Flanders, Belgium with an option to invest in a recycling facility[7]. Two real option analyses will be performed, following the structure proposed is section 2.2. Divergent results between profit maximization and welfare maximization will be analyzed and explained, emphasis will also be put on the impact the rebound effect has. Until now, studies have only taken into account the gross environmental impact reductions.

The monopolistic firm which is assumed in this research is called "*Plastic Ltd.*" and is specialized in recycling polypropylene (PP) and polyethylene (PE). Input data for the model are retrieved from the webpage of the National Bank of Belgium (National Bank of Belgium, 2018), from press-releases of recycling firms and from interviews with recycling firms. Flanders is chosen as the location for the potential investment because there is a lack of recycling capacity at present, most of the plastic waste streams are exported for processing.
Plastic Ltd. has the option to invest in a recycling facility which would recycle PP and PE waste bales to granulates. Bales – in this case PP and PE bales – are piles of PP or PE which have been sorted and pressed together. These bales are the input material for the facility and have to be bought at a certain market price which is
assumed to be fixed[8]. The output of the facility are granulates. Granulates are the 'raw material' used in production processes of plastic goods. After heating and pressing in the desired shape, these granulates form the plastic good. *Plastic Ltd.* will incur the demand uncertainty and experience this uncertainty via fluctuating selling prices. All other parameters are assumed to be fixed, both the operational cost per ton, including the procurement of the feedstock, and the nvestment costperton are assumed to be constant[9]. Parameters are shown in Table 1. A sensitivity analysis will be performed for the environmental externalities, the volatility and the constant Z. No sensitivity analysis will be performed for the investment and operational cost, results are not highly sensitive to changes.

Table 1. Case study plastics recycling: parameter values

parameter	value	unit
η	0.00001	/
Z	0.0001	/
r	0.1	/
μ	0.05	/
σ	0.2	/

[7] Currently no recycling facilities for PP and PE exist in Flanders, Belgium.

[8] This assumption represents reality, the feedstock is often supplied according to long-term contracts with fixed price

[9] Constant investment and operational costs are a simplification of reality. However, this simplification does not affect the results in a fundamental way

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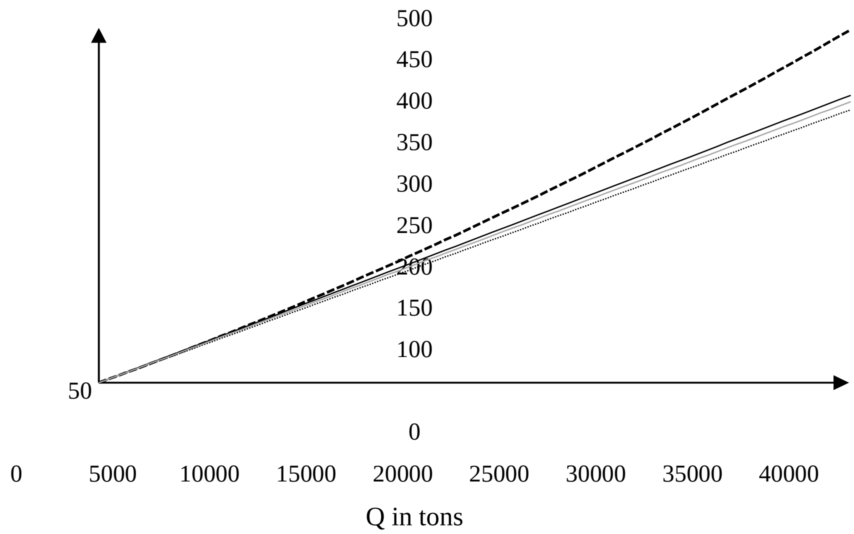
i	750	euro per ton
c	850	euro per ton/year
E	45.34	euro per ton/year

The aim of this paper is to analyze the influence of demand uncertainty, environmental externalities and the rebound effect on the optimal investment trigger X^* and optimal investment capacity Q^*. This analysis is performed two times; maximizing profit and maximizing welfare. It will be showed that the optimal investment trigger and optimal investment capacity are influenced differently by changing parameters or maximization issues. Because we do not have any historical market data, parameters to model demand and its accompanied uncertainty are estimated on aforementioned references but also calibrated so that the outcome approximates the real market best. This calibration is mainly performed via estimating η. A growing market is assumed, plastics are essential and the applications in which plastics are used grow every day. A sensitivity analysis will be performed on the volatility.

In the process of producing virgin and recycled PP and PE, many externalities are created. This study, however, concentrates on the environmental externalities only, with a particular focus on externalities linked to carbon emissions.to recycling, which should be valued and monetized to its social cost. The social cost of CO2 is a hotly discussed topic. Many different estimates have been calculated and the distribution of these estimates has a very wide range. In this research, a social cost of CO2 of 41 dollars per ton is adopted (Tol, 2009) (41 dollars is roughly equal to 33 euros). For now it is assumed that the social cost of CO2 is constant. The amount of CO2 kilograms saved by recycling is monetized and calculated according to expression (4). This social gain of recycling is internalized in expression (6), which is the non-linear cost function. Note that this cost function takes into account the diminishing returns to society of recycling *i.e.* the rebound effect.

The rebound effect is a correction on the amount of CO2 saved by recycling. As explained, the quadratic form $Q^2(t)$ is calibrated via multiplication with the constant parameter Z. Therefore, only this constant parameter Z has to be defined to calibrate the rebound effect. For now, a very small value is chosen, however, a sensitivity analysis will show the influence of different values of Z on the cost function.
Not taking into account these environmental externalities, including the rebound effect, would lead to inefficient investment timing and inefficient production levels. Therefore, both analyses take net environmental externalities into account by assuming they are fully internalized at the company level[10]. If only one of the two analyses would take these externalities into account, comparison between thresholds would be spurious. As a consequence, conclusions would be wrong and would lead to the adoption of socially inefficient decisions.

[10] For example by imposing a Pigouvian tax or according to the Coase theorem.



conventional cost function

cost function corrected for linear externalities

cost function corrected for non-linear externalities (Z=0.07) cost function

corrected with the EU ETS

Figure 1: Cost functions

Figure 1 shows four different cost functions, the correct cost function – that is the cost function equal to expression (6) taking into account environmental externalities of recycling and the rebound effect – is the non-linear dotted line[11].The full black line describes the conventional cost function, *i.e.* only operational costs without any externalities. Taking into account linear environmental externalities which are correctly monetized following (Tol, 2009) results in the linear dashed line. The full grey line is the cost function experienced when linear externalities are internalized following the monetization proposed by the European Union Emission Trading Scheme (EU ETS) (20 euros per ton CO2 emitted). This cost function approximates reality best as larger producing firms within the EU are subject to this scheme.

Figure 2 depicts the optimal investment trigger X^* calculated following expression (15)[12]. This investment trigger is reached at the tangent point between the ROA and NPV line. At this particular point, the option to wait is valued equally with the investment. Hence, a firm is indifferent between investing or waiting. Any point to the right of X^* signifies a situation in which the option of waiting bears lower returns compared to the investment, this region is called 'the investment region'

The opposite holds for every point to the left of X^*, these cases are typed by an option value which is greater than returns of the investment, this region is called 'the waiting region'.

[11] A high value for Z has been chosen for readability purposes.

[12] Figures will show the profit maximization case unless stated otherwise

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Both expression (15) and figure 1 express the optimal investment trigger in terms of X. As X is a measure which is difficult to interpret, a recalculation can be performed according to expression (A7). Recalculating X^* to the optimal price results in $P^* = 1\,384$, expressed in euros per ton. The value of the investment expressed in terms of the optimal price remains the same and is 11 195 178 986 euros. Note that this value is calculated by subtracting all future negative cash flows from all future positive cash flows and discount the
result to the time of the investment.

Figure 2: Investment value $V(X)$ and optimal investment trigger X^*

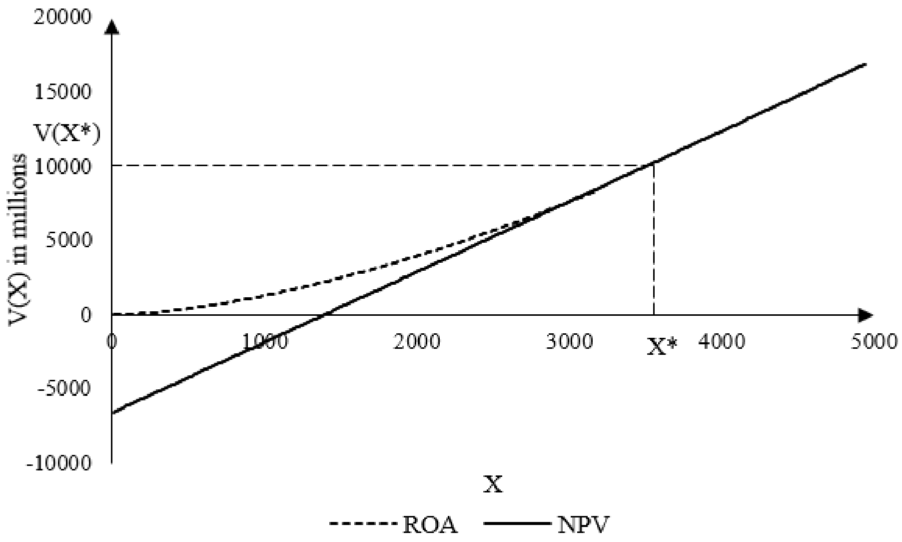

Figure 3 shows the curves determining the optimal investment capacity Q^* for any given level of X. As expressions (9) and (A12) mathematically show, the optimal investment capacity is dependent on the maximization objective. At the optimal investment trigger X^*, the optimal capacity to invest is 38 329 tons in the case of profit maximization and twice the capacity, 76 658 tons, in the case of welfare maximization. These capacities are the production capacity a plant should have in tons per year The fact that capacity doubles is inherent to this particular model, with its particular demand function. In general, we could say that capacity will increase significantly after maximizing welfare.

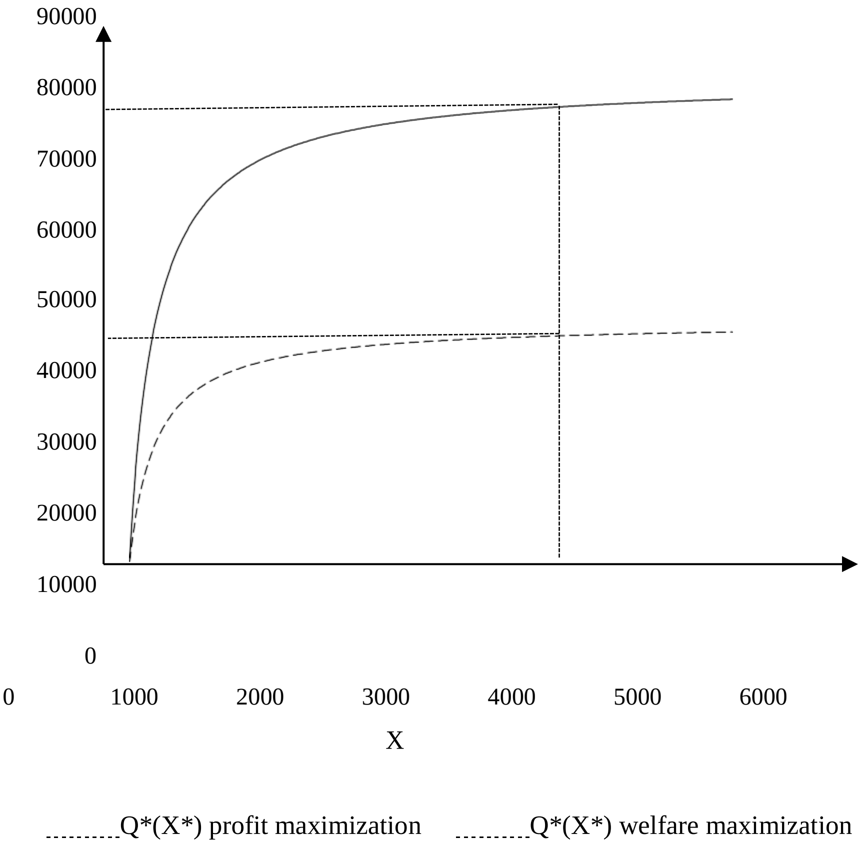

*Figure 3: Optimal investment capacity Q**

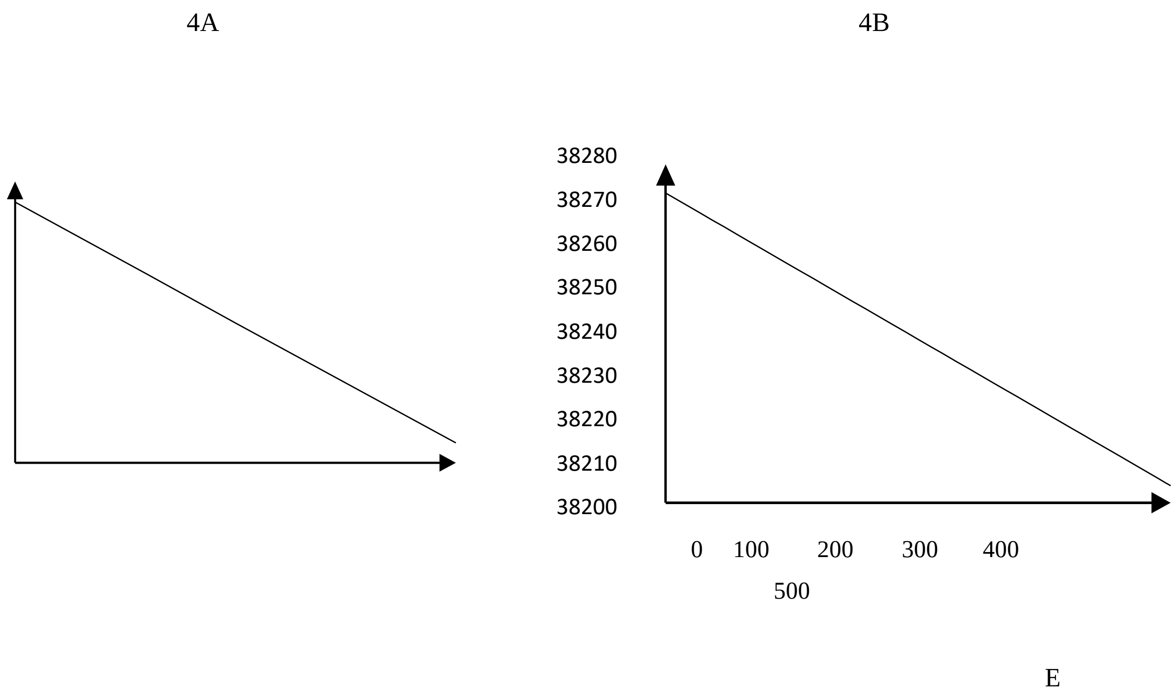

Figure 4: sensitivity for changing E

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Figure 4 shows the influence of changing net environmental benefits of recycling on the optimal investment trigger X^*, and on the optimal investment capacity $Q^*(X^*)$, we take the profit maximization case into account. The negative relationship shown in figure 4A is linear but could be non-linear when rebound effects are taken into account. The rebound effect would make this relationship to be diminishing[13]. Notwithstanding this effect, a negative relationship confirms the intuition that higher positive internalized externalities lead to lower investment thresholds experienced by the firm. The negative linear relationship shown in figure 4B follows the same ratio as the one of figure 4A. Higher internalized environmental benefits result in a lower optimal capacity. This is a common finding in real option analysis.

Because externalities have such significant impact on investment thresholds, a sensitivity analysis is performed, showing the influence of different values of Z on the investment thresholds. Higher values of Z correspond with a more pronounced rebound effect. This result corresponds with the results shown in figure 4A. Lower environmental benefits – that is higher cost function experienced – correspond to a higher investment threshold. A high value of Z means that the positive externalities are only internalized to a lower extend compared to a situation with a small value of Z

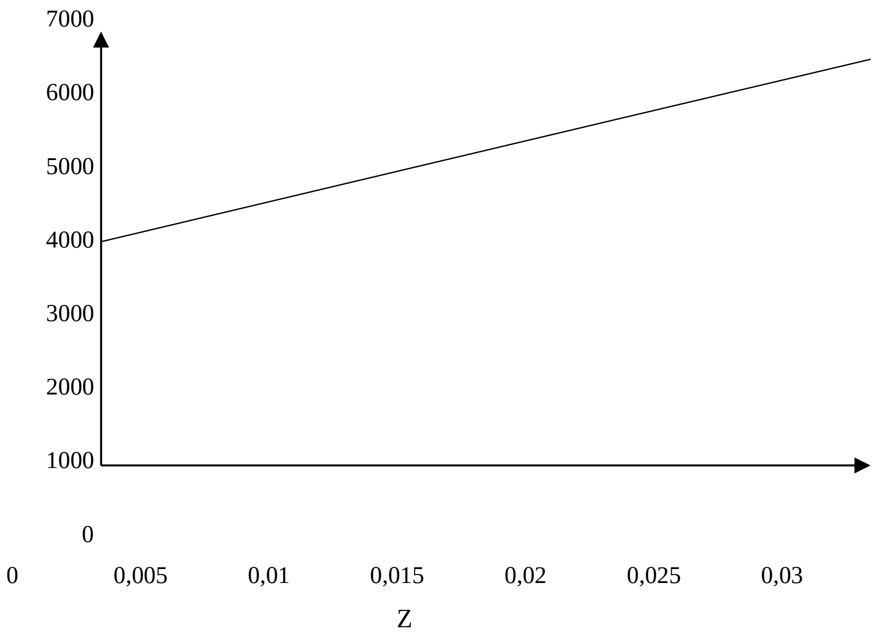

Figure 5: sensitivity for changing Z

[13] A rebound effect weighted with Z equal to 0.0001 is taken into account.

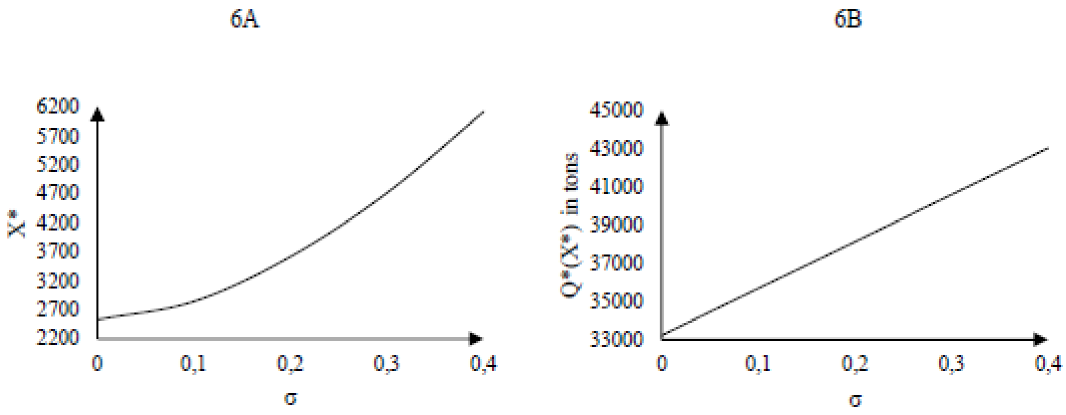

Figure 6: sensitivity for changing σ

Figure 6 shows the influence of a changing volatility on the optimal investment trigger X^*, and on the optimal investment capacity $Q^*(X^*)$. The non-linear positive relationship between uncertainty and optimal investment capacity (6A) is a general finding in real options (Dixit & Pindyck, 1994). Figure 6B is intuitively understandable: if uncertainty grows, investment thresholds will be reached at a greater value of X – a higher P in terms of prices, hence, a higher optimal capacity to invest in.

3.1 Poisson extension

So far, the model applied to the case study only considers demand uncertainty driven by the market. However, currently, the European market for recycling plastics also experiences legal uncertainty driven by Chinese legislation. This uncertainty is intrinsically different compared to the general demand uncertainty. Legal uncertainty manifests itself via market shocks. For this reason, we opt to write an extension in which legal uncertainty is also considered next to the general demand uncertainty. In order to understand why it's so important to consider this legal uncertainty, we first elaborate on the situation.

Plastic waste streams have systematically been exported to China and its surrounding countries since the 1990s. At this time, it was found that these waste streams could be recycled[14] and valorized, especially because, otherwise empty returning ships, could deliver these streams cheaply (A. L. Brooks, Wang, & Jambeck, 2018). At the same time, waste exporting countries were released form their waste management obligation, which would probably have resulted in landfilling or incineration (Velis, 2014). This situation has been going on ever since. In 2016, 123 countries together exported nearly halve of all plastic waste which was meant to be recycled. The Member States of the EU collectively, are the biggest exporting region in the world. More than halve of this fraction of plastic waste which is meant to be recycled was exported to China. As a results, China imported more than 25% of this fraction (7.35 million tons) (UN, 2018; ITP, 2017). Since 1992, China and Hong Kong together have imported 72.4% of all plastic waste, Hong Kong is often used as an entry port where

[14] Still, 1.3 to 3.5 million tons of plastic are estimated to be landfilled in the ocean annually by China (Jambeck et al., 2015).

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waste is redirected to China (A. L. Brooks et al., 2018).

The declining import percentages (72.4% - 25%) follow a downward trend which is explained by stricter import regulation issued by the Chinese Government (Chinese Government, 2018). The import policies stiffened over the years, in 2013 the "Green Fence" was introduced, a temporary regulation only allowing import of less contaminated waste streams. As of January 1 2018, new legislation is permanently banning imports of nonindustrial plastic waste (Chinese Government, 2018). This 'plastic ban' was experienced as a shock on the European market. Nevertheless, the legislative trend in China could have predicted such regulation *e.g.* China has one of the most progressive CE policies (Qi et al., 2016). Still, this study argues that there exists a legal uncertainty towards the latest Chinese regulations. Many of China's environmental policies are driven top-down, resulting in a lack of compliance (Qi et al., 2016). Therefore, the duration of the 'plastic ban' remains uncertain, any changes will struck the market as a shock again. For example, if firms in the EU invest in plastic recycling and China abolishes its 'plastic ban', EU firms will most likely not be able to compete with Chinese competitors. The investment will therefore be worthless.

The deadlock in which the European plastic recycling sector is caught, has not yet been solved. Many exporting countries did not have an alternative to manage their waste streams when China banned nonindustrial plastics. Other Asian countries are currently accepting European plastic waste. However, their recycling infrastructure is not designed to recycle Europe's plastic waste (A. L. Brooks et al., 2018). Hence, European investment in plastic recycling capacity is needed, especially if the aim of the EU is to follow its own plastic strategy[15](EC, 2018).

The original model takes into account the general demand uncertainty, modeled with a geometric Brownian motion which is a continuous stochastic process. However, legal uncertainty provokes market shocks. These shocks are not continuous, but occur as 'jumps'. Therefore, the extension will consider a model taking into account a mixed Brownian motion – jump process. The arrival time of jumps is modeled with a Poisson distribution. λ equals the mean arrival rate of a jump during a time interval of infinitesimal lengths of dt (Dixit & Pindyck, 1994). Hence, the probability of a jump equals λdt, the probability of a jump not occurring equals $1 - \lambda dt$. The geometric Brownian motion (2) introduced in the model is now augmented by the jump process:

$$dX(t) = \mu X(t)dt + \sigma X(t)d\omega(t) + \lambda X(t)dt \quad (19)$$

When considering Ito's Lemma (A4) and augmenting it with a jump process, equation (20) and (21) are obtained:

$$\frac{1}{2}\sigma^2 V^2 F''(V)dt + \alpha V F'(V)dt - rF(V)dt + \lambda F(V)dt = 0 \quad (20)$$

$$\Leftrightarrow \frac{1}{2}\sigma^2 V^2 F''(V)dt + \alpha V F'(V)dt = (r - \lambda)F(V)dt \quad (21)$$

15 Prohibit single used plastics

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Following above presented result and theory (Huisman & Kort, 2015), in this case the incorporation of a jump process boils down to discounting with a discount rate plus λ. The value of the investment (A2) is recalculated and equals (22):

$$\frac{XQ(1-\eta Q)-CQ+EQ-ZQ^2}{r-\lambda-\mu}-iQ \qquad (22)$$

The results of the model with a mixed geometric Brownian motion – jump process, *ceteris paribus*, can be obtained by substituting the discount rate r with u (23):

$$u = r - \lambda \qquad (23)$$

Following the above and expressions (presented in the appendix) for $X^*(Q)$ (13)(A10), the optimal investment threshold at any level of Q will increase due to the extra uncertainty λ of a market shock. The extra uncertainty results in a higher optimal investment capacity $Q^*(X)$ (9)(A11).

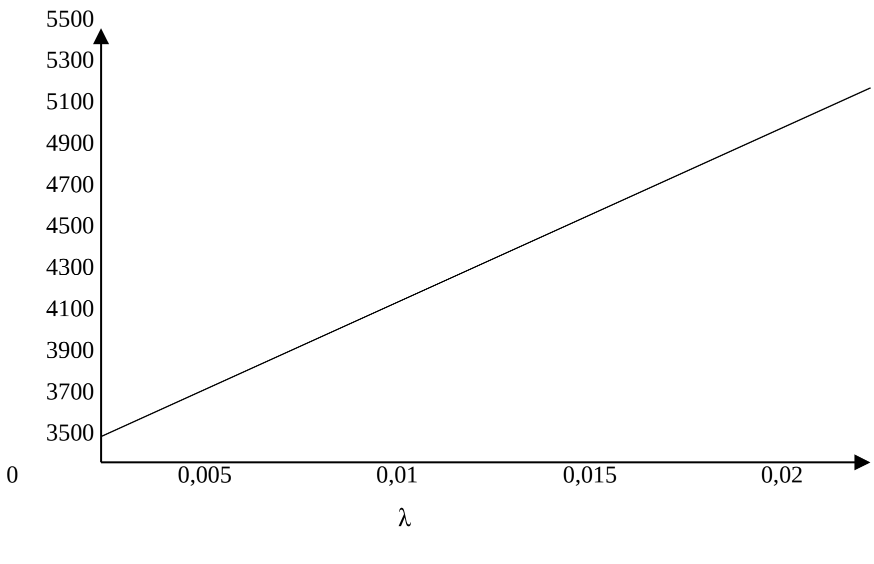

Figure 7: sensitivity of a changing λ

4. Conclusion and discussion

This research offers a ROA model tailored for investment within the CE. A decision rule is derived taking into account demand uncertainty, environmental externalities and possible rebound effects. The ROA is applied to

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a case study and performed two times – maximizing profit and maximizing welfare. It is found that welfare maximization leads to a higher investment capacity, but does not influence the optimal investment trigger with respect to profit maximization. The optimal investment trigger is found to be mostly influenced by demand uncertainty in addition to the cost function experienced by a firm. The cost function on its turn, is highly influenced by internalized environmental externalities and possible rebound effects. The extent to which environmental externalities are
present depends on the sector, likewise the presence of the rebound effect. This model is innovative on two levels; firstly, it is tailored to be used in the CE sphere. Secondly, rebound effects are taken into account, influencing the results obtained via the ROA, the incorporation of possible rebound effects in a ROA has never been performed before. Typically, rebound effects are studied to establish their existence and estimate their magnitude, this research studied rebound effects and their influence on investment behavior. We find that larger rebound effects negatively influence the effect of positive externalities – the investment trigger is delayed and the optimal investment capacity increases.

The developed model is applied to a case study in the plastic waste sector. Demand uncertainty for recycled plastic as well as environmental externalities and possible rebound effects are taken into consideration. The lack of investment in plastic recycling shows the desirability of applying the model, insights into this pending problem enable policy makers to take thoughtful actions. An extension is presented in which an elaboration on nonindustrial plastic is made. After the latest Chinese legislation 'banning' nonindustrial plastic waste, an extra form of uncertainty – legal uncertainty – is present. This increase of uncertainty results in higher investment triggers and larger optimal capacities.

Results of this researched have to interpreted keeping in mind that there are some limitations. The externalities internalized in this research are limited to CO2 externalities only[16], which is a pragmatic choice. Although the extent of these externalities is limited, the dynamic caused by internalization is present. Internalizing a wider range of externalities would increase the magnitude of the results but also the degree of uncertainty about correct values. Positive externalities will lower the optimal investment trigger and optimal investment capacity. This holds for both welfare and profit maximization.

Also the market structure and the rebound effect are limitations to this research. Throughout the entire research a monopoly is assumed, further research could take into account competitive market structures. The rebound effect incorporated into the model is limited to the direct rebound effect. Narrowing down the rebound effect to the direct rebound effect influences results. It is impossible to know in which direction results are influenced. Fortunately, however, the influence is most likely limited.

5. Appendix

This appendix is based on theory initiated by Dixit & Pindyck (1994) and insights gained by Huisman & Kort (2015).

Proposition 1

The value of the investment, depending on X and Q, can be defined by expression (A1). This expression equals the

[16] Other externalities could be resource depletion, marine litter etc

perpetually and continuously discounted cash flow minus the investment cost.

$$V(X,Q) = E\left(\int_{t=0}^{\infty} QX(t)(1-\eta Q)e^{(-rt)}\,dt - \int_{t=0}^{\infty}(QC)e^{(-rt)}\,dt + \int_{t=0}^{\infty}(QE)e^{(-rt)}\,dt - \int_{t=0}^{\infty}(Q^2Z)e^{(-rt)}\,dt - iQ\right) \quad \text{(A1)}$$

After perpetually and continuously discounting, expression (A2) is obtained.

$$\frac{XQ(1-\eta Q)-CQ+EQ-ZQ^2}{r-\mu} - iQ \quad \text{(A2)}$$

This expression is used to determine the optimal capacity to invest in and to determine the value of investment in case $X \geq X^*$.

Proposition 2

In case of $X < X^*$, the value of the investment equals AX^β. β is a solution of the quadratic equation (A3).

$$\frac{1}{2}\sigma^2\beta^2 + \left(\mu - \frac{1}{2}\sigma^2\right)\beta - r = 0 \quad \text{(A3)}$$

This equation is obtained after substituting Ito's lemma in the Bellman equation. This substitution leads to a differential equation (A4), which after solving equals (A3).

$$\frac{1}{2}\sigma^2V^2F''(V) + \alpha VF'(V) - rF(V) = 0 \quad \text{(A4)}$$

Solving (A3) leads to two possible solutions β_1 and β_2 (A5); we are only interested in positive solutions.

$$\beta_1 = \frac{1}{2} - \frac{\mu}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{\mu}{\sigma^2}\right)^2 + \frac{2r}{\sigma^2}} \quad \text{(A5)}$$

$$\beta_2 = \frac{1}{2} - \frac{\mu}{\sigma^2} - \sqrt{\left(\frac{1}{2} - \frac{\mu}{\sigma^2}\right)^2 + \frac{2r}{\sigma^2}} \quad \text{(A5)}$$

After calculating $Q(0)$, we know $\beta_1 > 0$ and $\beta_2 < 0$. Only β_1, referred to as β will be used in calculations for the investment value.

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A is a constant which, following theory equals (A6).

$$A = \frac{(XQ(1-\eta Q)-CQ+EQ-ZQ^2-iQ(r-\mu))(r-\mu)^{-\beta}}{(XQ(1-\eta Q))^{\beta}}.X^{-\beta}|X = X^* \quad \text{(A6)}$$

Proposition 3

Expression (A7) shows the inverse demand function. Using basic algebra the demand function is obtained (A8).

$$P(Q) = X(1-\eta Q) \quad \text{(A7)}$$

$$\Leftrightarrow D(P) = \frac{1}{\eta}\left(1-\frac{P}{X}\right) \quad \text{(A8)}$$

Computing the integral of the demand function between the boundaries ($Q = 0$, and Q at equilibrium price) results in the instantaneous consumer surplus (A9).

$$\int_{X(1-\eta Q)}^{X} \frac{1}{\eta}\left(1-\frac{P}{X}\right)dP = \frac{1}{2}XQ^2\eta \quad \text{(A9)}$$

The total expected consumer surplus, at a given level of X and capacity Q is described by (A10).

$$CS(X,Q) = E(\int_0^{\infty}\frac{1}{2}XQ^2\eta e^{-rt}dt|X(0) = X) \quad \text{(A10)}$$

Proposition 4

The optimal investment timing (A11) is not subject to profit or welfare maximization and thus remains equal to expression (13).

$$X_w^*(Q) = \frac{\beta}{\beta-1} * \frac{(i(r-\mu)+C-E+ZQ)}{1-\eta Q} \text{(A11)}$$

The optimal capacity invested in, is subject to different maximizations (A12). The optimal capacity under welfare maximization is obtained after maximizing total surplus $TS(X,Q)$ (18) and substituting (A11) into this maximization problem. (A12) equals twice the optimal investment capacity under profit maximization (9).

$$Q_w^*(X) = \left(\frac{-i(r-\mu)+X-C+E}{X\eta+Z}\right) \text{(A12)}$$

6. NOMENCLATURE

P	price
X	geometric Brownian motion
η	constant
Q	market quantity
μ	drift rate
$d\omega$	increment Wiener process
σ	volatility
r	discount rate
c	annual unit cost
i	unit investment cost
δ	summed discounted annual cost and investment cost
T	investment time
A	constant
β	constant
E	discounted environmental impact
d	displacement rate
Z	constant
λ	mean arrival rate

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Collaboration in industrial symbiosis to unfold circular economy potential: trends and opportunities

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Abstract

Industrial Symbiosis (IS) has been described as an industrial system that links up companies' exchanges of resources through collaboration in a context wherein the waste of a company becomes the supply for another company. By executing this approach, IS supports the transition from a linear to a model with closed loops systems better known as circular economy (CE). Thus, in order to promote IS in that area some factors play a key role, however, those same factors have very often become challenges that have constrained a fruitful development of IS at a global scale. So far, IS research have been heavily focused on technicalities to improve synergies among companies (material flow analysis, life cycle assessment, waste-to-resource matching and so on). Nevertheless, a successful transition to a CE would need to address more aspects related to IS than those based solely on material exchanges in order to deliver a wide-ranging implementation. One of those aspects has been related to collaboration, but collaboration may come in different forms and no single collaboration model has reached a consensus on whether that is a factor to drive successfully IS. So, it is crucial to identify what sort of collaboration approach would be more appropriate to unfold IS opportunities. Hence, this research carry out a systematic review of the scientific literature with the aim to detect the existing gaps in the literature regarding collaboration trends in IS. This was done by firstly, stablishing search keywords associated with the research area (CE, IS, collaboration, companies). Then, a query algorithm was created for the Web of Science database to ensure reliability, coverage and quality of the results. Then, the Matheo Analyzer software was used to process the results obtained through the search query. From the results, it can be deducted that collaboration among authors and countries are clustered in mainly three groups. The first group belongs to Asian countries (China, South Korea, Japan and Singapore), the second group are part of the European bloc (United Kingdom, Denmark, The Netherlands, Germany and Spain). Finally, the third group belongs to North America (Canada and U.S.A) displaying effective collaborations with the Asian group. Likewise, it was observed that collaboration as a topic has been underexplored under IS research. In that sense, some authors have stressed on the relevance of what they describe as non-technical obstacles such as lack of trust and cooperation between participating firms, knowledge gaps, rigid environmental regulations or lack thereof that needs to be addressed from an organizational theories' perspective more broadly. In that scenario, organizational perspectives might arise as a realistic path to upscale IS as organizational theories that integrate environmental and economic aspects in a broader approach in order to unfold CE potential.

Keywords: Circular Economy, Industrial Symbiosis, Collaboration, Systematic Review

1. Introduction

Circular Economy (CE) has been recognized for boosting growth within companies, cities and countries through the contribution of materials science, engineering, and systems design development (Pitt & Heinemeyer, 2015). Likewise, the CE has been carried out based on concepts such as reducing, reusing, recycling and materials' recovering in production and consumption activities to achieve closed loop systems (Kirchherr, Reike, & Hekkert, 2017). Consequently, CE's groundwork and its evolution over time would not be feasible without the existence of industrial symbiosis (IS) concepts and tools (Saavedra, Iritani, Pavan, & Ometto, 2018).

As such, IS is described as a system that gathers distinct industries in a joint endeavour to gain competitive advantage by linking exchanges of resources through collaboration in a context wherein the waste of a company becomes the supply for another company (M. Chertow, 2007; M. R. Chertow, 2000b). By doing so, IS supports the transition from a linear to a CE model by closing loops and thus, eliminating reliance on virgin materials (Abreu & Ceglia, 2018; Nasir, Genovese, Acquaye, Koh, & Yamoah, 2017; Saavedra et al., 2018).

Nevertheless, harnessing the opportunities that IS provides are not simple and it usually do not arise suddenly (Álvarez & Ruiz-Puente, 2017; Paquin & Howard-Grenville, 2012). The presence or absence of certain conditions might facilitate or impede IS dynamics (Boons, Chertow, Park, Spekkink, & Shi, 2017). Indeed, researchers have been studying IS in a larger context and therefore, have determined key factors to promote IS in technical, economic, organizational, social, and institutional scopes (Park, Duque-Hernández, & Díaz-Posada, 2018).

Most of these factors that might play a key role to promote IS have also become challenges that have constrained a fruitful development of IS worldwide (Akkerman & Zwicky, 2018). Regardless of existing technical and physical suitability and potential financial and environmental gains obtained in implementing IS (Doménech & Davies, 2011), escalating it to more regions worldwide would require an extensive collaboration amid partners that in several cases are being difficult to implement (M. Chertow, 2007),

Therefore, a successful transition to a CE would need to manage more aspects to implement IS than those based solely on potential matches on material exchanges in order to deliver a wide-ranging implementation. So, in order to observe current trends and potential gaps that are needed to be addressed to deploy IS at a far-reaching scale, it is necessary to identify what sort of collaboration approach would be more appropriate to unfold IS opportunities.

Hence, this research carry out a systematic review of the scientific literature with the aim to detect the existing gaps in the literature regarding collaboration trends in IS. This was done by firstly, stablishing search keywords associated with the research area (CE, IS, collaboration, companies). Then, a query algorithm was created for the Web of Science database to ensure reliability, coverage and quality of the results. Afterwards, the Matheo Analyzer software was utilized to process the results obtained through the search query.

Later, the results provided by the software were used to describe current trends of collaboration in an IS

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relationship context or lack thereof. Finally, an in-depth analysis was performed for each paper which met the following: a) have a direct relationship with the central topic of study (CE, IS and collaboration among companies)

b) provide clear information about collaboration in IS related to CE's development potential. The outcome of thisstudy is meant to elucidate the current trends and the foreseeable opportunities with a holistic approach that will consider collaboration perspectives of IS to fully deploy it in industrial activities.

2. Methods

2.2 Systematic literature review

To respond to the defined goal of detecting collaboration trends in IS, a systematic review of the scientific literature was proposed. This was due to that systematic literature review can improve methodological rigor whereas at the same time it underlines opportunities for further research (Briner & Denyer, 2012). In this study the search was limited to peer-reviewed journal articles published in English and conference proceedings. Then, the search was done following the next steps. First, the keywords associated within the research area were listed and afterwards, it was translated into a query algorithm in the Web of Science Core Collection database [v.5.32] which is regarded to be the most typically used and robust sources for bibliometric analysis (Kamalski & Kirby, 2012). Four groups of keywords were created with terms or synonyms with related meanings, these are shown in Table 1.

***Table 1** Keywords for the search query*

Groups	Keywords
Group 1: Circular Economy	"closed loop", "cradle to cradle", "circular economy"
Group 2: Industrial Symbiosis	"industrial synergies", "material flow", "waste to resource", "industrial ecology", "industrial symbiosis"
Group 3: Organisational	"organi?ation* theor*" "organi?ation* perspective", "management"
Group 4: Companies	"compan*", "enterpr*", "corporation*", "business*", "industr*", "firm*"

From these groups of words, a query or search algorithm was designed for the Web of Science Core Collection database [v.5.32]. A period of 19 years (2000-2019) was considered, and the search fields selected for the recovery of the scientific literature were; Topic (TS) and publication period (PUBYEAR). The final algorithm is shownin Table 2.

***Table 1.** Query algorithm.*

Query algorithm ((Group 1) AND (Group 2)) AND (Group 3) AND (Group 4))

(TS =("circular economy" OR "Closed loop" OR "Cradle to cradle") AND TS =("industrial symbiosis" OR "industrial synergies" OR "material flow" OR "waste to resource" OR "industrial ecology") AND TS =("organi?ation* perspective" OR "management" OR "organi?ation* theor*") AND TS =("compan*" OR "enterpri*" OR "corporation*" OR "business*" OR "industr*" OR "firm")) And PY=(2000-2019)

The outcome of the advanced search was then translated to a plain text document and processed in the Matheo Analyzer software. Symetrical networks, asymetrical networks and rank distribution graphics were elaborated through the software in order to observe scientific outputs (e.g. journal papers, conference proceedings), collaboration networks and trends concerning years, authors and countries.

2.3 Reviewing protocol

Once the first step of the systematic literature review described in the previous section was performed through Matheo Analyzer software a further reviewing protocol was applied to analyse scientific documents more in detail with the aim to observe potential opportunities in IS. Based on the query algorithm's outputs defined in Table 2, a query within the software was used to select scientific documents related to collaboration that were analysed in depth according to the aspects defined in Table 3

To ensure the quality of the results, a review performed manually of each of the papers selected was conducted and only those that met the following criteria were selected; a) have a direct relationship with the central topic of study (CE, IS and collaboration among companies), b) supply clear information about collaboration in IS related to CE's development potential. The application of the criteria in the reviewing protocol were carried out in two stages; initially reviewing the abstract to verify compliance with the criteria mentioned previously and keeping them on a waiting list. Afterwards a full reading was completed to decide whether to keep them or discard them.

Table 2. *Aspects defined in the analysis.*

Aspects analysed	**Description**
Year	Publication year of scientific documents
Countries	Countries associated with the authors
Collaborations	Description of any sort of collaboration between different stakeholders to boost IS implementation

3. Results and Discussion

3.1 Scientific outputs, trends and collaborations in IS

The query algorithm resulted in 181 scientific papers (journal papers and conference proceedings) provided by Web of Science database. Then, this result was transformed into a plain text that then was processed and further analysed in Matheo Analyzer Software. Firstly, with this information a network that presents the current associations within the same field called symmetrical network was created as can be seen in Figure 1. Although, some research papers related to IS had been published since early 2000's (M. R. Chertow, 2000b), it was not until 2003 that some research appeared in the scientific literature addressing either one or all of aspects covered in our search (CE, IS, collaboration and companies).

Nevertheless, around 76% of all scientific literature concerning the search aimed for this study has been

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growing dramatically since 2015 onward. Specially, 51% of the scientific outputs of the total sample is accumulated in only 2 years (2017 and 2018). Although, in the year 2019 only 17 papers has been published, this might be explained by time considerations given by the authors, which limited the search period until June 2019. Nevertheless, it is expected according to time and trends from previous years that 2019 will surpass the number of publications as shown in Figure 2. This exponential growth might be partially explained by some events that have taken place years before. One of them was the release of the communication titled '*Closing the loop – An EU action plan for the circular economy'* in which the European Union endorsed a transition to a CE to all of itsmember states to develop a model in which the value of products, materials and resources are kept within the systems they belong to for as long as possible (European Commission, 2015).

This according to the European Commission meant commitments on strategic approaches funded under the EU's Horizon 2020 research programme targeted to foster innovation, business opportunities and economic growth in areas such as critical raw materials, construction, industrial, plastics, food waste and public procurement among other sectors. Therefore, as part of European Commission's funding activities it was expected to obtain an extensive dissemination of knowledge (e.g. scientific communications) from that date onwards, partially explaining the rising trend underway since 2015. In the same ground, another reason to explain this trend might be explained by the launch of the Ellen MacArthur Foundation's first ground-breaking report titled 'Towards the circular economy' (2013) wherein it makes the case for an accelerated transition via CE's business reasoning, gaining interest from practitioners and scholars.

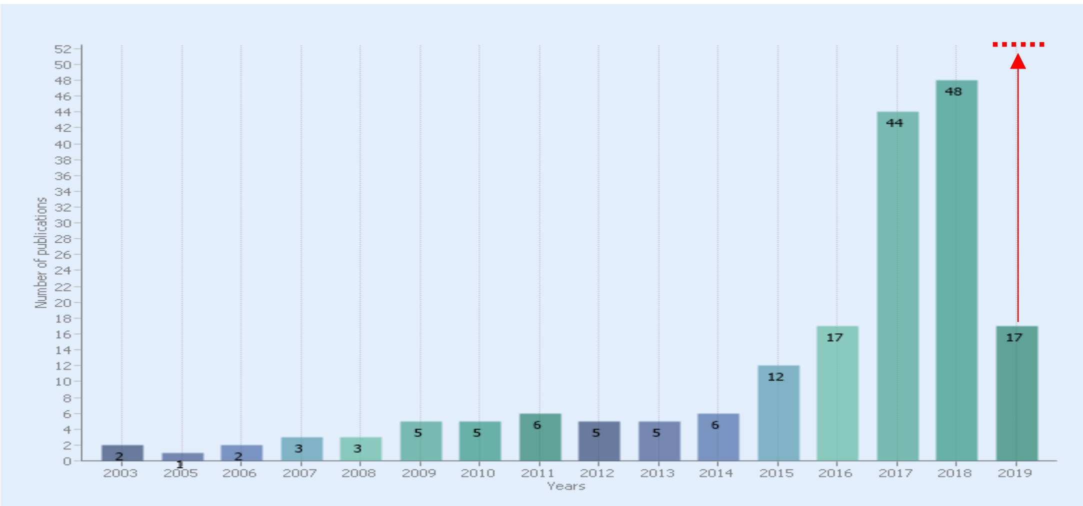

Figure 1. *Publications by year.*

Similarly, as can be seen from Figure 2, a collaboration network was created in order to observe fruitful collaboration. In particular, this network is an illustration of the relationships that exist between authors and countries made up of nodes and relationships. Hence, in this sort of mass information analysis, filters are necessary. These filters are 3; forms, connectivity and pairs and they support the analysis of scientific articles and more precisely the links that exist between the different elements.

For instance, forms (top-right number in each rounded rectangle) represents how many articles were published either by a country or an author. In that case, China is the country with the most articles published (40) for the period studied in this research (2000-2019), then followed by United Kingdom (22). Among authors Geng,

Y. outperformed the others (8 articles), followed by Romero, D (5 articles) and Fujita, T (4). Connectivity refers to the numerous authors with whom an author collaborated, being Geng. Y. the author whom collaborated with in most countries (China, Canada, the Netherlands, United Kingdom and Japan). Then, it follows Hermann, C and Hauschild, MZ (with four each). It can be noticed that different authors may collaborate in other countries regardless of the location where the IS is being studied, proving a borderless cooperation.

Lastly, pairs indicates numerous effective collaborations meaning the number of articles reached by two connections (number within ovals in every connection line). However, in the pairs filter, the Matheo Analyzer was set up to identify effective collaborations starting at 3 articles published. In that manner, a perception of effective collaboration could be distinguished leaving out those with one-time only and spontaneous cooperation between authors and countries.

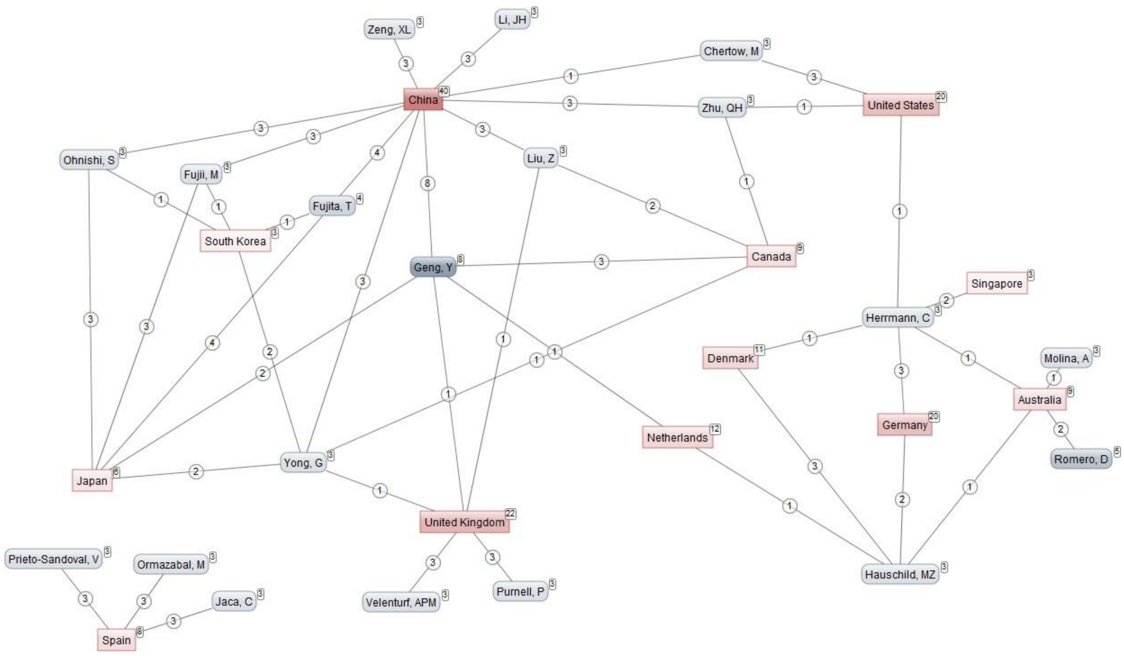

Figure 2. *Collaboration´s networks between authors and countries.*

In that sense, in China it was reached the most effective collaboration with the authors Geng, Y. (8 articles) and Fujita, T. with 4 articles (shared with Japan as well). The majority of the collaboration in which the most prolific author has been part of is related to empirical studies. For example, the author has studied in detail the particularities of the Japanese's eco-town program and the Chinese's eco-industrial park programme (Geng & Cote, 2004; Geng, Zhang, Côté, & Fujita, 2009; Van Berkel, Fujita, Hashimoto, & Geng, 2009; Zhu, Geng, Sarkis, & Lai, 2014). Moreover, the other studies he has been part of were meant to contextualize IS in other countries, partially explaining the connections with Canada and United Kingdom.

It is also worthwhile to observe that despite the network in Figure 2 was set up to display strong and effective collaborations amid authors and countries, Spain with its authors (Prieto-Sandoval. V, Ormazabal, M. and Jaca.

C) are the only ones isolated of the rest of the network. Although, there is a strong collaboration between these authors in Spain, they lack numerous effective collaborations with other countries and authors. This

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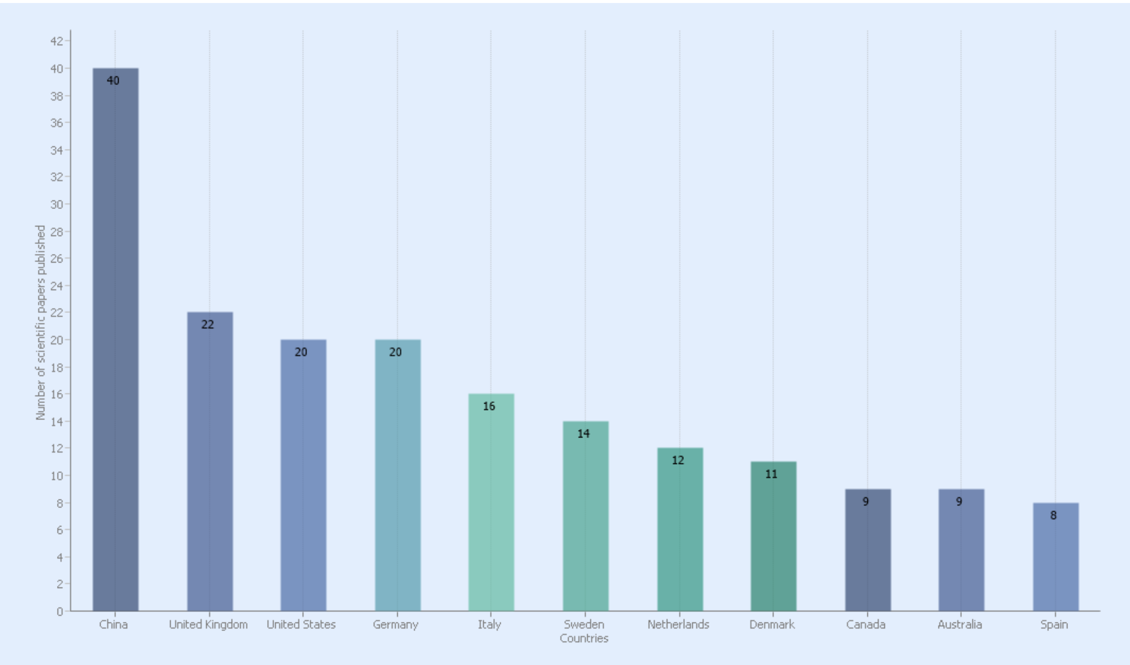
implies that effective collaborations can be reached within the same country, but a more robust collaboration is achieved when it is diversified in different countries (see Geng, Y with Canada, Japan and China). In general, it can be stated that three geographical groups of countries are recognized from Figure 2. The first group belongs to Asian countries (China, South Korea, Japan and Singapore), the second group are part of the European bloc (United Kingdom, Denmark, The Netherlands, Germany and Spain). Finally, the third group belongs to North America (Canada and U.S.A) displaying effective collaborations with the Asian group.

On the other hand, when it comes to number of scientific papers published by country (2003-2019), China leads the way with 40 publications authored by them (Figure 3). Nevertheless, the European countries as a whole gather around 57% of the research published during the last years. This fact is also backed by the CE action plan supported by the European Union which fosters research and innovation on this topic (European Commission, 2015). In China, the research has been focused on different industrial parks such as Tianjin Economic Technological Development Area (TEDA), The Suzhou Industrial Park SIP and Guitang Group (Mathews & Tan, 2011). All of this industrial parks had been part of the Eco-industrial parks' programme boosted by the central government which falls into the category of a top-down approach (M. Chertow, 2007).

Whereas, the United Kingdom as the second country with most publication on this field of research (22), have found its focus on the development of its pioneering 'National Industrial Symbiosis Programme' (Benedetti M., Holgado M., 2017; Domenech, Bleischwitz, Doranova, Panayotopoulos, & Roman, 2019). Some of them have initiated the symbiosis programme such as the Industrial district of the Humber Region (Velenturf, 2016). Likewise, countries such as Germany with its 'Spremberg paper mill' symbiosis case, Sweden with its Landskrona industrial symbiosis programme and Denmark's Kalundborg are among the European countries with successful IS implementation case studies (Jacobsen, 2006; Mirata & Emtairah, 2005; T. Vollmeier,



2015).

Figure 3. *Number of scientific papers published by country (2003-2019).*

Regarding core of literature's emergence, there has been a growing interest over the years. As such, Figure 4 depicts an asymmetrical network on existing relationships between two fields (years and keywords), following the same structure shown in Figure 2 (forms, connectivity and pairs). Instead of displaying information between countries and authors (Figure 2), Figure 4 is related to most common literature emerged over the last 3 years (2017-2019) on those topics covered in this study. Notwithstanding, CE is widely known nowadays, it was not until 2018 when it reached its publication's peak (37 publications). Some other terms such as industrial ecology and industrial symbiosis are growing in interest as well following the trend displayed by CE, despite the fact that industrial ecology and industrial symbiosis have been around for decades (M. R. Chertow, 2000a). This might becaused by the attempt to link closely the contributions of IS to a CE (Saavedra et al., 2018). Essentially, most of these IS studies described in the literature pursue an efficiency in resource consumption, which in most cases lead to a better resource efficiency, a waste generation cutback and a Greenhouse Gas Emissions (GHG) reduction (Saavedra et al., 2018). This precept is considered as the strongest link contributing to a CE (Domenech et al., 2019).

Moreover, as shown in Figure 4, there are concepts that in a less degree have been gaining attention over the years such as sustainability, resource efficiency, resource productivity and waste management. Increasing awareness of studies exploring waste and by-products' gain efficiencies through exchanges might explain the rising value given to enhance the value of residues in IS. Moreover, IS might involve similar concepts allocated separately as observed in Figure 4 that when placed together might explain the emergence of this literature's core, involving the basics of sharing assets such as equipment, human resources and knowledge as part of the core categories found in the literature (CE, IS and industrial ecology). From this network it has also been noted that research in different studies have addressed the need of innovations in relationships between years and resource flows' keywords (material flow analysis, resource efficiency and resource productivity).

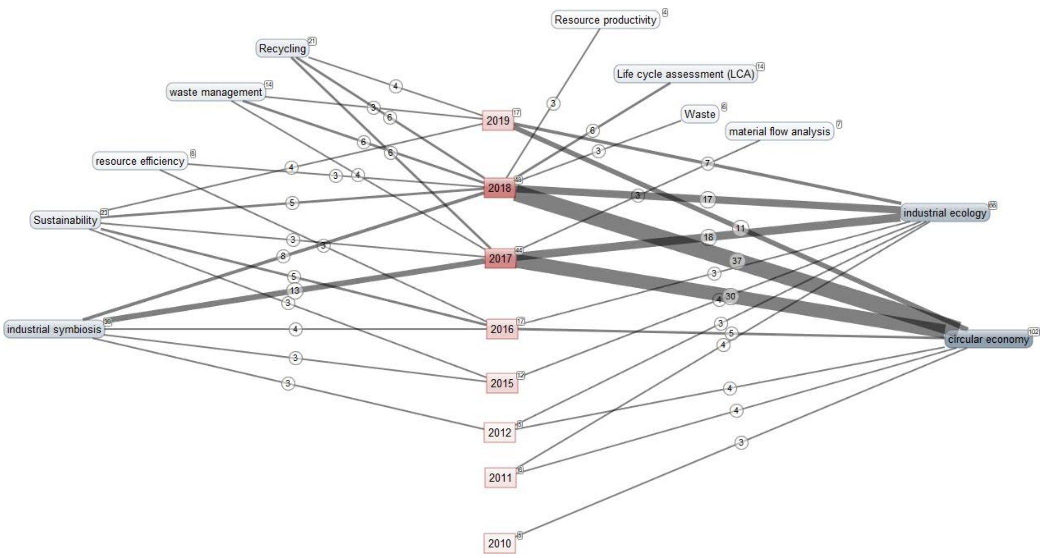


***Figure 4** Core of literature´s emergence*

The exponential interest in topics such as recycling, waste management, Life Cycle Assessment and sustainability might be due to the potential to remediate negative environmental and social impacts of IS and CE (e.g. pollution, greenhouse gas emissions and poor labour standards) (Saavedra et al., 2018; Walls & Paquin, 2015). For instance, the European Commission (2019) has foreseen IS as a strategy to accelerate the

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transition to the CE in order to create value through networks which support the involvement of different stakeholders to achieve "circularity" across systems.

3.2 In-depth analysis of scientific production

It was noted that keywords related with collaboration do not show any strong connectivity nor numerous publications on that topic to be part of core literature's emergence, despite the fact the word collaboration was implicitly part of the query algorithm. This proved that collaboration has been an underexplored topic in IS research. So, once an analysis of current trends and opportunities was undertaken, a further analysis was carried out to determine pieces missing in IS research. Later, the results for the query were processed through Matheo Analyzer software as shown in the previous section to complete an in-depth analysis. Thus, a filter called collaboration was applied to the query through the software to select those papers that comply with criteria shown in Table 3. A total of 52 papers were selected to establish the state-of-the-art in IS collaborations.

The most common factors emerged for companies to collaborate such as the proximity between companies which is deemed as a critical component as it facilitates the sharing of supplies and reduction of transportation costs have been found in this narrowed collection of papers (M. Chertow & Ehrenfeld, 2012a; Schiller, Penn, Druckman, Basson, & Royston, 2014). Nevertheless, from the analysis, some other insights were found such as the notions of coordination and management between companies in developing IS remains immature and joint opportunities are continually disregarded (Chertow & Ehrenfeld, 2012). Other factors have also been stressed such as policy- inducted incentives, time and coordinators (Mirata 2004). Some of the factors that could restrain the development of synergies are the limited production of sub product or residuals capable of being used, weak technical compatibilities, resistance to collaboration and the limited decision-making powers of the facility managers (Mirata 2004).

One obstacle to develop IS networks include data on the location, type, quantity of input materials and waste streams of the concerned geographical region. Moreover, the presence or absence of other conditions can facilitate or hinder IS dynamics (Boons et al., 2017). Facilitators include technical conditions, including the availability of secondary resources, economic conditions that incentive the search for cost savings and geospatial conditions such as distance among industrial companies. In particular, Walls & Paquin, (2015) have pointed out that an organizational research approach to IS would help to comprehend how environmental and economic value can be created through the IS collaborative network system, especially since they have attributed the establishment of IS to social factors.

The research of IS from this sort of organizational perspective are found scarcely in the literature, although, the studies have shown some recommendations to stimulate IS. For instance, Qi, Li, & Wang, (2009) concluded that a public-private partnership would be ideal to promote IS networks as it offers a stable institutional framework and good governance to empower stakeholders to share in the responsibility. Given this public-private association to promote IS partnerships, the authors stated that it would deliver a coordination and involvement of relevant stakeholders at the regional level to guarantee social, economic and environmental settings supported by state authorities, private business, NGOs, and public. In the same manner, M. Chertow & Ehrenfeld, (2012a) have also claimed for an understanding on why initial exchanges most often do not expand any further beyond the first actors involved in IS to successfully form a network. The authors also highlighted the need to understand the features of coordinating entities and cross-project comparisons based on contemporary work on organizational change and mostly they advocate for the role of self-organization in early success as an essential system goal in IS.

Other authors have proposed building institutional capacity for IS development. The term institutional capacity building is designed to examine the processes of developing ability amongst governance actors in a location to drive initiatives capable of shifting away from old practices (Healey, 1998). Wang, Deutz, & Chen (2016) described this concept from an IS perspective, which include sharing of knowledge resources; level of trust built up between companies; and players' ability to develop symbiotic partnerships. Then, the same authors applied institutional capacity building theory in a case study of an IS coordination network in an eco-industrial park and found that the network increased institutional capacity by promoting links across organizational divisions and by increasing various categories of knowledge for coordinating IS.

Aid, Eklund, Anderberg, & Baas (2017) supported the idea that waste management organizations should seek out to inter-organizational resource network as a model to nurture IS. The authors explained that in order to successfully develop inter-organizational resource management building up long-term partnerships are crucial to address uncertainties in implementing this sort of IS networks. This highlight goes in line with the future research area of interest proposed by Domenech et al. (2019), in which they assert for a deep exploration of the dynamics of IS to foster the upscaling of these initiatives.

In addition, there are still barriers which are often of non-technical nature; such as lack of trust and cooperation between participating firms, knowledge gaps, rigid environmental regulations or lack thereof, and uneconomic waste-to-resource exchanges which includes end of life processes such as collection and recycling (Low et al., 2018). For instance, in the European Union (EU) waste cannot be treated to become a product, and in many countries, there is not a well-defined regulation about the ‘‘end of waste’’ products of compostable materials.

Some of these conditions that restrain the development of synergies are the limited capacity of transforming a company´s waste into feedstock to another company, weak technical compatibilities, resistance to collaborate amid companies and the limited decision-making power of the facility managers (M. Chertow & Ehrenfeld, 2012a; Mirata, 2004). Similarly, Low et al. (2018) and Walls & Paquin (2015) have stressed on the relevance of what they describe as non-technical obstacles such as lack of trust and cooperation between participating firms, knowledge gaps, rigid environmental regulations or lack thereof that needs to be addressed from an organizational theories perspective more broadly.

4. Conclusions

As can be seen, collaboration in IS literature gained visibility in the early 2000's, however, different theories have tried to approach how to stablish a successful implementation of IS, which differs depending on multiple factors. Although, IS has been extensively explore throughout different approaches to understand the particularities involving this field, most of them are based on technicalities and data from resource exchanges. Likewise, collaboration networks has been created to expand the knowledge on industrial symbiosis. Though, the networks and the publications released from this cooperation are mainly based in developed countries such

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as in Europe or China.

Therefore, the knowledge obtained from these countries comes from very often the same successful IS cases (e.g. National Symbiosis Programme in UK, Eco-industrial park programme in China, Denmark's Kalundborg and so on). This pave the way to set the target from other perspectives wherein non-existent or incipient IS case has arose. In that scenario, organizational perspectives might arise as a realistic path to upscale IS as organizational theories that integrate environmental and economic aspects in a broader logic in order to unfold CE potential. Thus, it is clear that one piece of this puzzle has been missing in order to stimulate IS across companies. Given

that organizational theory has been claimed as the piece missing to uncover IS potential, this research is expected to offer a new insight by testing this hypothesis.

This study claims for a further exploration on how to improve collaboration in Is in order to unfold CE potential. Especially, the research should be focused on inter-organizational perspectives as IS works as a systemic approach rather than individual cases, so it would allow to generalize the features that governs IS in a wide-reaching context.

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Cross Cutting Policy

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Forms of ecological embeddedness in a shared social ecological system

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Abstract

Sustainable natural resource management in social-ecological systems involves a great diversity of actors, often gathered in boundary organizations in an effort of shared governance. Nonetheless, conceptions of sustainability may vary widely among them. Institutional theory has studied differences in problem understanding from the perspective of the actors' different institutional embeddedness. We argue that the ecological embeddedness of actors might also play a role in their understanding of natural resource management issues. Yet we know little on the ways in which modern institutional actors relate individually to their ecological context and how it influences their understanding of ecological matters. We offer to take a first step in that direction by raising the following question in a modern institutional setting: What connections do institutional actors of a social-ecological system have with the ecological components of that system, and how does that condition their understanding of ecological matters? To that end, we pursue an exploratory qualitative study with members from French river basin committees.

Keywords: Social-Ecological Systems, Ecological Materiality, Embedded Agency, Ecological Embeddedness, Sustainable Natural Resource Management

1. Introduction

The ecological crises our world is facing and is about to face in the 21st century can seem daunting. And the role organization and management studies have to play in coping with those crises has already extensively been argued for (Whiteman, Walker, & Perego, 2013; Hoffman & Jennings, 2015). We know from previous institutional theory studies that when organizational fields form around environmental issues, different interest groups pursue institutional work on how those issues should be interpreted (Hoffman, 1999). Today, conceptions of sustainability vary still widely among practitioners and scholars (DesJardins, 2016; Lankoski, 2016; Bansal & Song, 2017). Therefore, it seems necessary to focus more deeply on the determinants of an institutional definition of sustainability, as "addressing topics like 'ecologically sustainable organizations' requires first understanding how consensus is built around the meaning of 'sustainability'" (Jennings & Zandbergen, 1995, p.1016).

In contexts of institutional complexity, numerous papers have underlined the impact of individual agents' institutional embeddedness on their interpretation of a problem (Zietsma & Lawrence, 2010; McPherson & Sauder, 2013; Ansari, Wijen, & Gray, 2013). But in Social-Ecological Systems (SESs), and even more so with natural resource management, institutional or social (i.e. "human") factors do not exist in a vacuum, but rather ecological components and institutions impact each other and are strongly interrelated (Ostrom, 2009). Nonetheless, studies of the ecological embeddedness of institutional actors have remained marginal and limited to extreme cases

(Whiteman & Cooper, 2000). Institutionalist studies on actors' embeddedness have not included ecological materiality conceptually yet.

To fill this gap, we explore the following research question: What connections do institutional actors of a social-ecological system have with the ecological components of that system, and how does that condition their understanding of ecological matters? Members of river basin committees share both an institutional context (the basin committee), and an ecological context (the river basin). Their empirical study allows us to dig deeper in the micro-foundations of institutions (Lawrence, Hardy, & Phillips, 2002; Gray, Purdy, & Ansari, 2015) and focus our attention on individuals not only as embedded in institutions, but also in a material, ecological context. Our paper is in line with numerous calls for research to include physical or ecological components analytically in management studies (Boons, 2013; Starik & Kanashiro, 2013; Whiteman et al., 2013). Studying the ecological embeddedness of actors can shed a new light to the issue of embedded agency (Zietsma & Lawrence, 2010). It also contributes to extend the current research on materiality and institutional work towards "a considerably richer view of materiality" (Cloutier & Langley, 2013, p.364).

1.1 Ecological materiality in institutional studies

The inclusion of materiality in institutionalism remains marginal although argued to be necessary (Jones, Boxenbaum, Anthony, 2013; Monteiro & Nicolini, 2015) , as "understanding the role of material objects in relationship to institutions has been recognized as an important but under-examined issue" (Lawrence, Leca, & Zilber, 2013, p.1028). We agree with these calls for research on the importance of materiality. Yet again, even when a concern is expressed for the study of materiality in organization and management studies, it mostly tackles issues related to human-made or -induced material. The literature collected shows concern for the impact of technology or other human artifacts (Barley, 1986; Gawer & Phillips, 2013; Monteiro & Nicolini,

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2015) on institutions. We contend that this vision of materiality is too narrow to understand the material conditioning of institutions. In this paper, we are concerned with the materiality that exists independently from humankind and its institutions, and even preceded them in time, namely ecological materiality.

1.2 The ecological embeddedness of institutional actors

We contend that actors in SESs are not only institutionally, but also ecologically embedded (Whiteman & Cooper, 2000). Mirroring approaches to institutional embeddedness (Dacin, Ventresca, & Beal, 1999), we view ecological embeddedness as all the connections an actor has with his ecological context that prescribes or constraints his thoughts and actions.

Whiteman & Cooper (2000) developed the construct of ecological embeddedness from the analysis of a specific single case, the Cree tallymen in Canada. This depicts an extreme manifestation of ecological embeddedness which may not be directly applicable in non-indigenous modern empirical settings. We propose to see how well this construct translates in the context of collaborative river basin management. Further, Whiteman & Cooper conceptualized ecological embeddedness as "the degree to which a manager is rooted in the land—that is, the extent to which the manager is on the land and learns from the land in an experiential way" (2000, p. 1267). To open up the construct to this new empirical context, we think in terms of forms of embeddedness rather than in terms of degree.

2. Methods

2.1. Research setting

Our study is based on French river basin committees (comités de bassin), often referred to as "water parliaments". Those institutions were created in the 1960's, in an effort to establish collaborative governance of water resources at the scale of hydrographic basins. The metropolitan French territory is covered by seven basin committees. The basin committees are instituted by law, which specifies their composition, involving diverse actors, such as local authorities, industrialists, farmers or NGO activists. They are not purely consultative as they formally debate, and vote plans that river basin public agencies are in charge of implementing. The regulation of those institutions is complex and has evolved since their inception in the 1960's, nonetheless the overall logic remains the same. Figure 1 represents in a simplified model the organizational structure of river basin institutions.

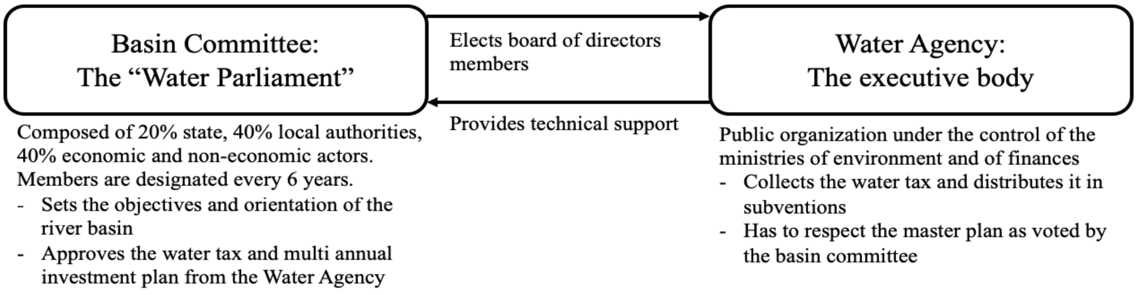

Figure 1 – The organizational structure of basin institutions

2.2. Data collection

Data collection took place from 2017 to 2019 in two river basin institutions, *Loire-Bretagne* and *Seine-Normandie*. We attended two plenary committee sessions, one in each river basin studied, as well as a board of directors meeting. Semi-structured interviews were conducted with current or former basin committee members and with water agencies employees. Interviews were gathered with a mix of theoretical and snowballing sampling to catch the diversity of interest groups in the committees, both economically and geographically (cf. table 1). 26 interviews were face-to-face, and 9 on the phone. They lasted about an hour and were audio-recorded in all cases but one. Follow-up mails were collected when necessary to confirm analysis. The data collected also includes archive data (minutes of plenary sessions), as well as additional reports gathered based on recommendations from interview participants. Those were used to understand the institutional context in which basin committee members evolve.

Table 1 Interviews conducted by river basin and type of actor

	Water agency	State	Local authorities	Economics actors (industry, farmers…)	Non-economic actors (NGOs)	Total
Seine-Normandie	1	1	3	5	4	14
Loire-Bretagne	2	3	4	6	5	20
Other	1					1
Total	4	4	7	11	9	35

The interview protocol was developed to invite participants to reflect on their personal experience as participants of river basin committees. Questions were initially inspired by an institutional perspective (Selznick, 1949) as well as by the collaborative governance literature (Newig, 2007; Reed, 2008). If the topic had not been raised before, a final question dealt with their concern for the natural environment.

2.3. Analysis

We decided to pursue qualitative research on the topic as our aim is to "challenge taken-for-granted theories and expose new theoretical directions." (Bansal, Smith, & Vaara, 2018, p. 1189). Our research has a primary focus on the individual level but keeping in mind the institutional context in which individuals are located (Gray et al., 2015). We transcribed interviews verbatim and coded them with NVivo, writing memos all along the process, in an effort to go from data to theory (Strauss & Corbin, 1998). We approached the data with the following question in mind: "How do those actors relate to the river basin? What do they understand from it? Do they differ from one another on those matters?"

In the interviews, elements of internal and external power struggles relating to the participation process surfaced. Those aspects were left for further research to focus on the existence of different understandings of environmental issues at the individual level.

3. Results and Discussion

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3.1. Institutional context of members' ecological embeddedness

The institutional approach to river basin management has greatly evolved since the creation of basin institutions in the late 1960's. It went from strict resource management to more holistic environmental approaches, with the introduction of concepts of ecosystems and sustainability. Advances in natural sciences on ecological systems and the education of basin committee members played a role in this institutional evolution. Nonetheless, scientific knowledge remains incomplete and hence leaves room for members to have divergent opinions on what is "right or wrong" in environmental decisions, and what are priorities.

> *"So, what is not necessarily clear is what is meant by 'good condition' (of rivers). Are we sticking to regulations? Or are we going to fantasize a bit further?"* (#1, Industry)

Basin committees have emerged as institutions with shared rules and goals. And yet lasting conflicts are reported, which do not seem to erode with time despite a consensus-seeking policy.

> *"Debates, cutting remarks- especially between agriculture and ENGOs representatives- have been going on for a long time. I can tell you that they were already there in 1997, and probably before that too."* (#19, water agency)

Previous research has found that belonging to a group greatly influences one's perception of environmental risks (e.g McCright & Dunlap, 2011). Indeed, basin committee members of certain groups oftentimes defend a common position on environmental problems. But group affiliation does not tell the whole story of how individuals relate to environmental matters. Members might be constrained in their decisions by their representation mandate, but they oftentimes have diverging views from their groups' regarding environmental matters. Interviewees refer to an individual "concern for the environment" or an "environmental sensitivity". An industrialist reports that he is happy to come to the basin committee meetings as no one shares his interest in water back in his company (Interview #21).

Further, not only members of Environmental NGOs (later on, ENGOs) position themselves as "environmentalists". Members of groups who sometimes oppose ENGOs do so as well, such local authorities, farmers, and so on.

> *"I am very environmentalist. Well I think about the environment all the time."* (#11, agriculture)

3.2. Forms of individual ecological embeddedness

Having presented briefly the institutional context of river basin committees, we investigate what are the different attitudes basin committee members display towards the river basin. Again, we focus on any connection a member has with his ecological context that conditions his thoughts and actions. Ecological embeddedness englobes cognitive, emotional and material aspects. Of course, an individual's ecological embeddedness and his institutional embeddedness are not fully independent. An individual chooses his career path based on personal interests. Likewise, being part of a group implies being exposed to certain experiences that influence the individual relationship to the ecological context.

Based on our observations we identified three archetypes of members (see table 2), distinguishing them by how they relate to the river basin, cognitively, emotionally and physically. The terminology developed is based on how some of those members present themselves ("colibri", "atheist", "environmentalist"). Regarding the "colibri" term, we keep here the French 'colibri' word (hummingbird in French) for its context-specific value. This term relates to a social movement created by Pierre Rabhi (Rabhi, 2010).

Table 2 Synthetic archetypes of ecological embeddedness with the river basin seen among interviewees

	Colibri	**Resource environmentalist**	**Environmental atheist**
Mostly seen representing…	ENGO, fishermen	Industrialists, Agriculture	Water agency, state
Claim of pragmatism	Yes	Yes	Yes
Concern for the well-being of populations	Yes	Yes	Yes
Conceptualization of the river basin			
What constitutes a problem	Threats to the identity, or intrinsic nature, of water or of the river basin	Threats to the benefits humans obtain from water resources	Threats to social peace
Water means…	An element of emotional, or spiritual dimensions, a support of life, a part of one's identity	H^2O	H^2O
Nature means…	A complex system damaged by human activities	The environment that co-evolves with human activities	A pristine state that does not exist anymore
Negotiation means…	An unavoidable battle, but not leading to the solution for environmental issues	The only way to reach a solution that satisfies requisites from men and the ecosystem	A mean to reach social peace among actors of a river basin
Lived experience with the river basin			
Reported origin of first involvement with river basin management	Personal experience with a river (childhood, family…)	Concern for impacts of environmental problems on human populations	Professional path
What is interesting about water	Its intrinsic nature (ontology)	Its usefulness and technicality	Its usefulness and technicality
Dependence of own livelihood on ecosystem	None to high	None to high	None
Ecological understanding			
Assessment of the evolution of the state of French river basins	Catastrophist	Mixed	Mixed or progressing
What is society needs to sustain from the river basin:	As much as possible the river basin ecosystem, with its original forms of life and functioning	The ecosystem services necessary to guarantee human activities, and the population's health	Whatever keeps social peace
What could society give up on:	Current modes of production and consumptions, economic growth	Some autochthon fauna, a 'perfectly clean' river basin	Whatever societal pressure does not require

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This table is by essence simplifying. Those characteristics appeared together in our data, nonetheless an individual might be matching characteristics across archetypes. Not all members of the groups mentioned match the corresponding archetype, and more archetypes might exist. We will develop later on in the findings and discussion why characteristics tend to coexist.

Most members of the basin committees, albeit their differences of socio-economic background and views on river basin management, show some personal concern, either for a specific place, for *'water'* or for environmental matters. Participating in basin committees takes time. Topics are complex and require work from the members, and most of them are not paid for this.

> *"There is a motivation that must be some kind of pride to belong to such an institution, having the impression to defend water, nature, the environment etc. Otherwise they wouldn't go through all that trouble. I admire a lot those people who ... who devote time to that."* (#22, water agency and state)

Yet, digging into how members talk about environmental matters, we can see that they have different ways of engaging with environmental matters. This would not be correctly captured if we thought of this engagement as a continuum going from individuals with a low level of engagement with ecological matters, to individuals with a high level of engagement. To explore this further, we map as "ecological engagement" any individual interest for ecological matters.

Basin committee members talk very different ways about water or rivers. When asked about their motivation to participate in the basin committees, *colibri* members mention water emotionally as a building part of their identity, with a certain fascination.

> *"I ended up in water from a very young age, as a child. And in the same way as salmons are imbued with their birth environment, well I remained imbued with the theme of water since my birth almost."* (#2, ENGO)

Colibris mention a direct exposure in their youth to a river, along with relatives, such as fishing or simple observation of nature. Those members do not only have an interest in water in general, but also important childhood memories linked to a specific place, a river. Non-*colibri* members might also have had contact with rivers in their childhood. But they did not mention such memories to explain their involvement as basin committee members. It seems that it was not relevant to them to describe their involvement with water topics.

Resource environmentalist for example developed an interest in water topics later on, for more utilitarian reasons. This interest is not intrinsic to the nature of water but relates to the challenges water can represent for societies:

> *"The oil crisis made me think about the big shocks that society would experience in the coming years. And I quickly realized that after oil, it would be water."* (#27, local authority)

Finally, environmental atheists dealt with water or environmental topics along their career due to their professional background. Those did not report an emotional origin of their choice of career path or to their commitment as basin committee members, although it might have existed, or they might have developed a personal attachment since.

Regarding the influence of livelihood dependency to the ecological context, we find that seeing material dependency as a single dimension predicting ecological engagement is incorrect. The exact nature of material dependency seems to be a better predictor: what exactly does the activity require from the river basin, how clean do they need water to be, how they leave water once they have used it.

> *"I am lucky not to have an activity comparable to that which at the moment defends its interests even if ... its cereal or animal production forces to pollute the water resource."* (#31, shellfish farmer)

3.3. Differences of understanding on ecological matters

> *"Everyone has one truth."* (#20, expert member)

Throughout the debates, all members refer to reason and pragmatism to defend their position. In the "*schools of water*" that are basin committees, scientific knowledge and expertise are highly valued, and expected to inform decisions. It is possible in those institutions to change someone's opinion by simply presenting him or her with new information. It is nonetheless reportedly more an exception than the rule.

Scientific information is not understood the same by all members. First, this information is quite technical. Participants who do not have a solid scientific background report struggling to process the information given to them. Aside from that, information accuracy is frequently contested. Finally, even unquestioned information can lead to different conclusions.

In our analysis, we distinguish the differences of views based on disagreement on facts, based on different interpretations of accepted facts, and based on different priorities.

3.3.1. Disagreement on facts: the limits of natural science

Basin committee members disagree on environmental assessments, as well as on causality statements. Participating in committee meetings implies having access to a large amount of scientific information, in the form of reports and presentations. Yet, despite being exposed over long time periods -sometimes decades- to the same information, members form divergent opinions of what is going on in their river basin. Opposite views can be seen, for example, regarding the evolution of the ecological condition of rivers, as seen in these two quotes:

> *"You have things that nobody says and that I spend my time saying.* [...] *The rivers have never been this clean in France."* (#10, state)

> *"The year 1964 and even before, well, the state of the environment, in spite that, was infinitely better than now. There isn't even a comparison."* (#2, ENGO)

There are also opposing statements on the feasibility and outcomes of environmental action. For example, we find debates regarding water retention for irrigation, or organic farming practices. Factual disagreements lead to strong emotional reactions and accusations. The other opinion is discarded as irrational or dishonest, a "belief", or "negationism".

When confronted with facts they don't agree with, members do not always answer by opposing contradictory facts but also by questioning their validity and asking for more research. The necessity to think about the geographic and time scale of the river basin, with its inherent complexity and unpredictability, leaves space to question many assertions. When looking into the future, actors notably include climate change as a source of uncertainty.

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"All those are decisions ... where we will see the consequences in 50 years. So, are those good or not? ..."

(#3, agriculture)

In a modern setting, 'walking the land' (or, in our case, observing the river directly) plays a role but is not the main way for members to gather information. This does not mean that the knowledge acquisition of basin committee members is disconnected from their presence in one territory. Territorial understanding is actually called for by the basin institutions:

"The advantage of water agencies is that there are representatives from everywhere. [...] (They) *have that vision, at the same time knowing a bit the documents, and then at the same time knowing their land, their territory and the environmental issues of their territory."* (#17, agriculture)

Territorial affiliation influences in two ways a member's information gathering. First of all, we consider territorial information to be information that would not have been accessed by the member if he was not locally socially and ecologically embedded. Secondly, the territorial anchorage influences the way the member makes sense of both the territorial and the general information given to him:

"An operator like me from a semi-urban area, an operator from a very urban area, from Paris, or from a completely rural or maritime area, we have different sensitivities. So, when facing the same objective fact, we do not feel the same." (#18, local authority)

Territorial affiliation can also act as a hindrance on the ability of an actor to make sense of some kind of information. Actors naturally understand their dependence on the actions of upstream actors, as they see water coming from them, but it does not mean they instinctively grasp the impact of their consequences on actors downstream. Much more than a matter of vested interest, it seems to be a matter of cognitive awareness:

"You see, the sea is something else, but also because we struggle to make the connection between ... freshwater environments and the sea." (#25, ENGO)

Inhabitants of river basins do not by themselves gather ecological information covering the whole river basin, nor do they know how to read information from a system perspective. Some form of education or technical knowledge is necessary to make the leap from seeing ecological elements of one's local territory to understand them in the context of the river basin system. A good example is a water agency employee getting upset at people rejoicing to see the Rhône River full in summer. Where they saw a sign of abundance and good ecological health, she saw the melting of glaciers upstream.

3.3.2. Difference of interpretation of materiality

Aside from contested information and territorial understanding, facts can be questioned by none, and yet be interpreted differently by everyone. In this case, different knowledge appropriation is profoundly linked to intrinsically different relationships to the ecosystem, i.e. to different forms of ecological embeddedness.
Striking differences on interpretation exist regarding what facts are problematic or not. Among such facts, we find rain patterns, floods or evolutions of biodiversity such as with invasive species.

"What makes the Loire ... It's its extreme irregularity. And so, flooding is not a disaster, it's not all that,

> *it's constituent. It is the Loire. That's it. Like the Nile. Egypt is the gift of the Nile; well the Loire Valley is a gift of all that."* (#30, local authorities)

> *"So, what is an invasive species? Well it's a species that we introduced, and which takes the place of native species. I say, isn't it just evolution? It comes from far away and it took… isn't it a bit of racism regarding species coming from far away?"* (#26, industry)

To summarize, what makes something a problem to each archetype? For a *colibri*, anything threatening what they see as part of the identity, or intrinsic nature, of water or of the river basin would be seen as a problem. For resource environmentalists, problems are events threatening the benefits humans obtain from water systems. Finally, environmental atheist would perceive events threatening social peace as a problem.

Problem identification depends on how members conceptualize ecological elements. We will exemplify this with the example of conceptualization of 'water'. *Colibris* refuse to see water as a simple resource as it evokes an exploitative mindset. In water they see life, mystery, beauty. In that, they are radically different from both resource environmentalists and environmental atheists who conceptualize water in a plain physico-chemical manner, as H_2O particles and the services they serve for ecosystems. The two following quotes illustrate that opposition of view:

> *"Water, in fact, is mystery. There is what is above water, and then there is what is below the surface of water. And we do not always see on the surface of water even when it's transparent. And beneath the surface of water is the place of mystery."* (#2, ENGO)

> *"Water has a great characteristic, something very special ... Water, how to say, it's never consumed. We never lose water. It's only transformed.* […] *It's useful to many things; it's never lost. One must always know: Water is a zero-sum equation."* (#18, local authority)

If a member sees water purely as a resource for human activities, then an increase in evaporation is not necessarily a loss: it's a change in the spatio-temporal distribution of that resource. Meanwhile, if one is attached to a specific ecosystem, to its characteristics (e.g. landscapes, biodiversity), as the spatio-temporal distribution of water alters those, then any change of water evaporation pattern from that system becomes a loss. That explains the existence of heated discussions on water retention for agriculture going over decades.

Another important difference of interpretation exists regarding the notion of nature. Environmental atheists consider that there is not such a thing as a natural environment, or Nature, that it stopped existing as soon as humans started manipulating it.

> *"The natural environment does not exist anymore. We no longer have a natural environment in France. »* (#6, water agency)

They advance that, contrarily to other members, they do not "believe" in nature. Hence, to them, many ecological restoration objectives referring to going back to former natural functioning, seem irrational. If one thinks about the natural aspect of a system as irremediably lost once altered by humans, that opens to many more potentially desirable futures than if one believes that going back to a preexisting state is possible. What is left to matter are resources for human well-being.

> *"Today, it is a discourse from believers. They say, 'nature must be protected because we depend on it'. I say that the French natural environment is totally artificial. A little less than in Switzerland. A little less*

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> *than in Holland. But it is totally- there is nothing natural."* (#5, water agency)

Colibris and resource environmentalists do not see nature as gone. *Colibris* see it as not enough understood or respected. Meanwhile, resource environmentalists see nature as molded by humans, without it stopping being nature, in a negotiated interaction. This vision sees men not only as destroying but also as potentially contributing to nature by their interventions:

> *"Nature reacts, so our job is fascinating."* (#3, agriculture)

3.3.3 Difference of priorities

A key nuance among members is on the timeliness of solutions. Contrarily to other members, *colibris* hold that there is a time constraint, a time limit in the future regarding ecological systems' resistance, and that the current rate of change is not fast enough to avoid a catastrophe.

> *"The human species must ... do more- well do more than currently of course. Whether it is for global warming or the protection of biodiversity. Because shortly there will be only us left on this planet. And (laughs softly), it won't be habitable anymore."* (#14, ENGO)

This catastrophic outlook is tightly related their particular emotional attitude towards river basin management matters, to what makes them 'colibris'.

> *"It may not be much what we do, I do not know. In this respect I would be rather pessimistic, but that does not prevent me from going there. How could I say... This is the story of the 'colibri': There's a forest fire, all the animals are watching the forest burn - you know that story, right? Well, at least I would have done what I could. That's it. So maybe it's - sometimes I say to myself, it's completely ridiculous, I should give up on everything and go fishing as long as there are still fishes."* (#25, ENGO)

Colibris display intense emotions, such as despair, resignation, and a deep sense of moral duty. Although they are convinced that their participation in the basin committees will not help avoiding that foreseen catastrophe, they see no better option. They are in a unique position compared to other members who believe that the current system will be able to bring timely solutions, who are satisfied with incremental progress, and do not see a problem in postponing the achievement of some ecological objectives.

On the opposite, environmental atheists and resource environmentalists believe increased ecological objectives are meant to push things to be even "prettier", with no notion of the necessity to avoid a crisis, but as driven by a political will.

"Participant: *We have to getting into ... Well, into grotesque reasonings.*

Interviewer: *What sort of reasoning?*

> Participant: *May everything be beautiful; may everything look clean. We have to take care of everything at the same time, etc. It's ... well, it's not reasonable."* (#1, industry)

Environmental atheists and resource environmentalists believe that basin committees are making progress, although they acknowledge many challenges. For them, the push of *colibris* for radical change in regulation and practices is due to a higher degree of requirement regarding how "clean" the environment should be. Non-*colibri* members present the degree of requirement from *colibris* as unreasonable, utopist and unnecessary. For *colibris*, that is the pursuit of the current situation that is unrealistic and impossible. All members, once again, claim to have a pragmatic approach. We will see in the following sub-section how that influences their way to approach negotiation on ecological topics.

Based on those differences in priority, basin committee members have different levels of satisfaction with the participative process of those committees, and different attitudes regarding the institutional discourse advocating for constant consensus-seeking. Here again, *colibris* stand out. They frame the participative process as a necessary struggle, as a fight, which is not enough to reach a solution but is the best option they have. In this confrontation, they count on the external pressure of the broader population.

> *"Constant consensus ... really allows things to be pfff ... extraordinarily slow.* [...] *It's compulsory in a way, but it does not change things. Not fast enough."* (#31, shellfish farmer)

Non-*colibri* members see consensus as the way to reach a satisfactory decision, to prevent or tame conflicts among competing uses of the river basin, as explained by this member.

3.4. Ecological beliefs: What environment do we wish for

Basin committee members acknowledge that there are other visions than their own and refer to them with strong words. They sometimes resort to pejorative terminology of believes or ideologies to mention other members, such as *"technocrat lunatics"*, *"ayatollahs"* or *"fanatics"*.

> *"Behind this observation, there is the fact of an ideology, the ideology, I would say, of growth, the ideology of production."* (#2, ENGO)

Both *colibris* and resource environmentalists can also apply the lexical field of belief or ideology to themselves, sometimes viewing their participation to the basins institutions as a "calling".

> *"And then I immersed myself in everything related to the environment. I discovered that I was a polluter, an unbelievable sinner. I thought, but it's not possible what ... what I'm doing. And suddenly I got passionate. So then for 2-3 months, I couldn't sleep."* (#16, water consumers NGO)

We understand those strong expressions as a sign of equally strong attachment to one's own individual belief system regarding river basin management. This belief system seems to point to a central concern all members share: All participants claim to be looking for the wellbeing of human populations, sharing a concern to guarantee the future of next generations.

> *"And it's for tomorrow, for our children and our grandchildren. I myself have a grandchild who is 4-month old. What world are we going to leave him?"* (#15, agriculture)

This shared concern is not enough to reach an agreement as there are different ideas of what human populations need from the ecosystem.

In the language of basin institutions, the ecological water renewal system (i.e. evaporation, precipitation, river flow, infiltration) is called the "big cycle" of water. Meanwhile, the "small cycle" of water is the man-made treatment system to obtain potable water (water extraction, drinking water treatment, adduction, wastewater treatment). The way basin committee members evoke this classification gives us a sense of how they approach environmental matters. Environmental atheists when asked about the place left to the natural environment in the debates, directly refer to debates on the big cycle. For them the system created by humans to guarantee the wellbeing of the population is distinct from natural matters: what is needed from the river basin is mainly usable

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water, and everything else is secondary. Big cycle investment is justified in the sense that it brings ecosystem services to populations.

> *"At the time, if you like, there was so much to do, that the natural environment was almost secondary. [...] We knew there was something to be done, but it was really not a concern at all. There was so much to do, I call it primary, it may not be well-said. But most of the effort from everyone was mostly on water supply, water treatment, and sanitation. First wastewater collection, and if possible, wastewater treatment, but wastewater treatment, of course, with a link to drinking water."* (#8, water utility)

Colibris perceive that humans need much more from the natural system than just drinking water, including mental wellbeing and not just physical wellbeing. Natural settings, as notable landscape, are presented as vital for psychological health and not a decorative anecdote. This perspective makes sense as those members are also the ones who report an emotional experience with a natural place. We hypothesize that a person who perceives having retained some important benefit -may it be emotional, psychological, or material- from an ecosystem will assume that this sort of benefit is important to human populations in general. In that sense, members rightfully call themselves or others "believers". Different archetypes of ecological embeddedness are linked to different belief systems regarding what ecosystems are, and what human populations need from them. In that sense, even self- proclaimed environmental atheists have a belief system. That is why we suggest that the identified archetypes are internally consistent, i.e. there are internal logics on why some characteristics coexist in each individual.

4. Discussion

Our analysis shows that ecological materiality does condition the thoughts and actions of institutional actors, through their ecological embeddedness. Indeed, throughout our analysis, we see ecological materiality influence committee members, may it be an initial trigger of interest (youth experience), or through territorial understanding. Further, we see that this ecological embeddedness is a matter of forms rather than of extent. We have identified 3 archetypes, though more may exist. We now draw theoretical implications from that analysis and develop recommendations for academic and practitioners.

4.1. Ecological embeddedness as forms rather than an extent

From an institutionalist tradition, we approached ecological embeddedness as all the interconnections actors have with their ecological context that prescribe or constrain their behavior. When compared to Whiteman and Cooper's (2000) work on ecological embeddedness (see table 3 for concept correspondence), some dimensions naturally appeared again in our data, such as the adherence to ecological beliefs or the gathering of ecological information.

But it would be a platitude to say that French basin committee members do not rely on their physical presence in ecosystems the same way as Cree tallymen do, nor do they adhere to the same set of beliefs. Therefore, we had to reframe the dimensions outlined of Whiteman and Cooper (2000) to match our findings.

Table 3 – concept correspondence of ecological embeddedness

Ecological embeddedness as in Whiteman and Cooper (2000)	**Actualized ecological embeddedness**
Personal identification with the land A sense of being a place	Ecological engagement (interest) Material dependence on an ecosystem Personal identification with a place Personal identification and commitment with ecological matters
Adherence to ecological beliefs Ecological reciprocity Ecological respect Ecological caretaking	Ecological beliefs What do human populations need from the ecosystem
Gathering ecological information The earth as teacher Ecologically experiential	Ecological understanding Natural sciences as a teacher Territorial information gathering (first-hand and vicarious)
Being physically located in the ecosystem Management by "walking out"	Territorial affiliation and emotional experiences

We reframe the dimension of 'personal identification with the land' in a broader concept of ecological engagement, which englobes all forms of interests an actor can have regarding any ecological object. With the term "engagement", we underline that actors are not only characterized by how they identify to an ecological object, but also by the level of personal commitment (may it be material, financial, or emotional) they show towards that object.

Our data only had scarce direct references to physical location in the ecosystem. It is indicative that in a modern setting, where people spend little time outdoors. This does not mean that members are independent from ecological contexts. Treating an actor as ecologically embedded or not does not provide valuable insights, just as it wouldn't to say an actor is institutionally embedded or not. One would ask "in which institution or field? With which position?". Similarly, concerning ecological embeddedness we should ask: "Does he materially depend on this ecosystem? What for? What is his emotional relation to it? What sort of environment does he think we need?"

4.2 A way forward to overcome differences of ecological understanding

In participatory processes, Selznick (1949) warns us against the dangerous drift of organizational goals when those include "unanalyzed terms". The management literature oftentimes focuses on companies' efforts as turning to measures that are "greener", or more "sustainable" (e.g. Martinez, 2015). Those papers focus directly on what makes companies decide to implement those measures, without questioning what makes them more beneficial to "the environment". This approach assumes that what an environment in a good state is or should be is unambiguous, that actions can clearly be classified as being beneficial to the environment.

In our study, we show that this is too much of a simplistic story. In a case like the one studied here; basin committee members are educated in a boundary organization to the challenges their river basin faces (Fan & Zietsma, 2017). They are exposed to the same scientific information, as well as to a representative diversity of interests and opinions of actors with whom they share that river basin. And yet, they disagree on what practices

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represent good environmental management. They don't just disagree on the accuracy of ecological statements, they disagree on the interpretation one can make from those statements, and they disagree on priorities. They even disagree on what the natural environment is or is not. And those actors have been exposed to the same debates for years, even decades for some of them. To sum up, we see that ecological engagement and beliefs go beyond knowledge acquisition.

Natural sciences alone cannot inform with an absolute certainty which practice is "good" or "bad" from an ecological perspective. This is partly due to the complexity and unpredictability of ecosystems such as river basins, which is amplified due to their interaction with human societies (e.g. Rice, 2013). Indeed, the ecological outcomes of environmental measures such as ecological restoration are oftentimes very hard to assess (e.g. Morandi, Piégay, Lamouroux, & Vaudor, 2014). But further than that, natural sciences cannot answer the questions raised when confronting different ecological beliefs, different visions of what human societies need from a river basin. In our research context, some members are aware of that:

> *"We do not even defend nature. We defend a vision. We defend an idea. Because, again, it is not nature that has mandated us to go there."* (#30, local authority but identifies as ENGO)

When we are talking about sustainability in the context of river basin management, we can wonder again, "what is to be sustained?" (DesJardins, 2016). Is it a certain form of drinking water and food supply? Is it landscapes with all their characteristics? Or is it a certain form of biodiversity as inherited by millions of years of evolution? The list of wishes could go on forever. The answer cannot be "all of the above" as those goals have different material implications. The current model of agriculture, for example, alters biodiversity and threatens the quality of water resource for drinking water supply. Old historical buildings, which are part of cultural landscapes, such as old mills, pose a threat to the fauna. Tough choices have to be made and, again, ecological materiality sets conditions: All cannot be kept as it is, not because we do not want to, but because ecosystems work one definite way and not another, regardless of how we conceptualize them. In that, we contest an approach to commons that would be purely socially constructed (Ansari et al., 2013). We cannot wish ecological constraints away.

In the end, discussions boil done to one question: Keeping ecological constraints in mind, what environment do we wish for our society in the future? And to its uncomfortable corollary: What are we willing to give up on? As it is, this last question is never openly phrased in basin committees. It could nonetheless help to think about the necessary trade-offs societies face.

5. Conclusions

The organization and management literature is suffering from a paucity of vocabulary when dealing with ecological matters. We have spent great time dissecting different forms of institutional logics (market, community, etc.), yet considering what is "environmental" or "sustainable" as just one big block. Just as colons setting foot on America and calling all tribes "Indians", management scholars still approach environmental matters as one obscure continent. Our study shows that no study on sustainable environmental management should take a practice advanced as "sustainable" at face value.

Our study re-conceptualizes ecological embeddedness closer to realities which can be more familiar to management academics. It shows how a "modern" Western institutional actor relates to his surrounding ecosystem: a human spending less time outdoors, but ecologically embedded nonetheless, in his own way.

More precisely, our findings develop on different ways to relate to an ecological context and resulting ecological belief systems.

Having observed how disagreements and misunderstandings on ecological issues can persist in spite of shared organizational goals and scientific information, we propose a new approach at the individual and institutional level to ecological goals, keeping ecological materiality in mind. We should strive not to ask ourselves 'what do we wish for?' but rather 'knowing the ecological boundaries, what are we willing to give up on?' This approach might prove fruitful to prepare for upcoming climate disturbances.

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The profile of human time allocation across hierarchical levels of organization as an emergent property of societal metabolic pattern

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Abstract

The metabolic pattern of human societies is associated with the expression of a set of societal functions resulting in a given profile of human time allocation across different levels of analysis. This profile is determined by a combination of socio-economic, biophysical and cultural factors. The analysis of the entanglement of these factors is essential to identify the option space for a radical transition to more sustainable consumption and production patterns. This analysis shows that the current definition of concepts such as “work” or “leisure time” is ambiguous and it depends on the chosen framing of the analysis. A metabolic and systemic perspective, addressing the complexity of societal and economic functions across different hierarchical levels of organization, allows to understand the contingency among the different uses of time within the given option space.

This paper uses a well-established accounting framework - Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) - to illustrate the existence of impredicative relations between different profiles of “allocation of human time” defined at different levels of analysis. The amount of human time invested in the various compartments of the society must respect relations of congruence between the relative sizes of these compartments across scales. The total amount of hours of human time per year associated with the population of a given society – i.e. the budget of human time – has to be allocated among the various competing activities in a zero-sum game: if a larger share of time of human activity is spent in expressing a given function, less human activity is available for the others. A multi-scale analysis can be used to identify trade-offs and possible “bottlenecks” associated with changes in profiles of human activity at the individual level (work vs leisure), economic sectors (investments in work vs technical capital), the whole society (reducing the size of primary sectors vs reducing the size of the services and household sector). The discussion is illustrated with empirical data.

Keywords: Human Time Allocation, MuSIASEM, Production and Consumption Patterns of Society, Societal Metabolism, Social Practic

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1. Introduction: the structure of this paper

The concept of metabolism refers to the whole set of activities that, in a living system, guarantee the production and use of both energy and materials required for maintenance and reproduction. For this reason, this concept represents a useful framing for the study of the factors affecting sustainable production and consumption in human societies. Human activity is a key factor determining and controlling the metabolic pattern of human societies. For this reason the profile of allocation of human time in a society can be analyzed in relation to the role that the various categories of human activities play in the expression of the pattern. This paper starts with a brief overview of the evolution of the studies on human time allocation (Section 2) focusing on what has been studied about human time allocation and why. There is a long history of studies dealing with the pattern of allocation of human time. However, this analysis has always been carried out for specific practical purposes – i.e. looking for a purpose of human activity at the time. First, the use of human time was studied in relation to particular functions to be expressed – production of goods in the economy - in order to understand how to improve the associated activities. Then, the use of human time was studied as a source of information about the characteristics of the society and the well-being of individuals – to generated indicators of the type of society. In Section 3 we claim that a distinct emerging transdisciplinary field should be considered in relation to the analysis of the role that the profile of allocation of human activity across different levels of organization plays in the process of self-organization of the society. More specifically the concept of metabolic pattern of social-ecological systems can be used to explore the entanglement of the factors affecting the profile of human activity across the different functional compartments of the society. In Section 4 we illustrate the methodological approach developed to perform the analysis of human time allocation from a metabolic perspective. This analysis can be carried out, in quantitative terms, by using a specific accounting framework called Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM). This framework is capable of identifying different sets of constraints (at the level of the individuals – i.e. demographic structure – and at the level of the society – i.e. economic structure) determining the option space of a given profile of human time allocation. In Section 5 we use the protocol of accounting based on a characterization of different types of constraints to study the profile of allocation of human time using empirical data. First, we provide a comparison of the profile of human time allocation in EU countries and China to show the effects of the constraints in different situations. Then we provide profile an analysis of the profile of human time allocation within the metabolic pattern of Spain. Finally we visualize an overview of the set of impredicative relations over factors determining the profile of human time allocation in relation to the establishment of a dynamic balance, within the metabolic process – i.e. human time invested in the catabolic side must be congruent with the human time invested in the anabolic side. A section of conclusion wraps-up the discussion flagging the implications of this study.

2. A brief overview of the evolution of studies on human time allocation

The approaches to the analysis of human time uses have been evolving reflecting the progressive change of interest for it. In fact, time is just one of the attributes that can be used to characterize human activity and it is the attribute that refers to its limitedness. In fact, one of the first systemic interest in its accounting could be found in the earliest attempts to use the scientific method to the analysis of human labor in the production processes and to its management: the so-called Taylorism or scientific management of labor. Taylor developed time studies, which basically consisted in the repeated observation and measurement of the time required by workers for developing specific tasks of the production process (Taylor, 1911). His goal was basically to improve labor productivity in order to achieve labor saving in industrial processes (Mitcham, 2005). Measuring working time not only permitted to control the workers and the production, but also to better coordinate and organize all production processes. In this line, Gantt created his chart, a scheduling technics, allowing an optimization of the organization of multiple activities to be carried out to achieve a final result that has become the basic foundation of production planning (Gantt, 1919). However, the idea of boosting productivity through scientific management of human activities has not been the exclusive strategy of capitalist systems. The very same concept has been adopted also by the centrally planned economy of Soviet Union (Lenin, 1951), although it was more a rhetoric and ideological statement rather than an actual strategy to boost productivity (Wren and Bedeian, 2004). In general terms, the systemic interest in human time accounting could be associated with the industrial revolution and the massive introduction of fossil fuel machinery. In fact, the expansion of what Lotka called "exosomatic metabolism" (Giampietro et al., 2012; Lotka, 1956) changed dramatically the energetics of human labor: from a source of power, human labor became a source of control required to make effective the flows of applied power generated by exosomatic devices - i.e. technology fed by fossil energy (Giampietro et al., 1993; Giampietro and Pimentel, 1991, 1990). Before the industrial revolution working time was not really a big issue because the different factors affecting productivity of pre-industrial modes of production were uncontrollable and more associated to the will of the nature and goods (Naredo, 2015). The dramatic change of the productivity of work in industrial economies implied a change in the perception and the measurement of time: from a system of characterization based on the observation of natural cycles (moon cycles, solar cycles), human perception and measurement of time moved to the observation of technical devices: the "o'clock time" (Ogle, 2015; Stephens, 2002). This move can be easily explained with the practical problems associated with the commodifying of work when labor is paid largely by the clock. This "productivist" or "chrematistic" concern for the relevance of time could be just summarized in the popular expression "time is money" that can be found in the opening statement of the essay of Benjamin Franklin (1748) "Advice to a Young Tradesman". Nowadays, the interest in accounting of labor time goes beyond the concern for productivity, all national statistical offices collect information and reports of working time in the market through Labor Force Survey in national accounts. The analysis human labor has included new definition of relevance such as social issues as unemployment (a concern exploded in the USA in the 30s after the Great Depression) or the quality of the work place as its temporality, working hours (full or part job), wage, age, sex, race, educational profile or the economic activity developed (Hansen, 2007). Still, these statistical data report labor market human activity (that is around 10-15% of total human time in a society Giampietro et al., 2012) that represents "less than half of all productive activity" (Pentland et al., 2002, p. 9) when considering also other forms of work outside the market. In fact, feminist economists criticize the current use of the term "work" to refer only to the economic activities taking place in the market perpetuating a gender bias in the assessment of workloads (Mayordomo and Carrasco, 2000). The focus on paid work entails a systematic neglecting of the domestic family work providing care, affection and overall tasks related with nurturing or reproductive work. This use is hiding the work mainly done by women (Smith, 2013). When considering paid and unpaid work all together many scholars arrive to the conclusions that women work more than men (Fisher and Robinson, 2011). Unpaid work activities carried out in the private sphere "cannot be calculate in monetary terms and yet are absolutely essential for the continuance of life"(Carrasco and Mayordomo, 2005). In this line many feminist scholars claimed for a new valuation of

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time and quantification of the importance of labor, starting by contradicting Franklin: "Time is not money! If anything, it is more important than money. The time we have to care for one another is more […] precious to us than anything else in the world. Yet, we have more experience accounting for money than we do for time." (Folbre and Bittman, 2004, p. 1). Analysis of unpaid work in relation with gender and poverty are also essential in development studies through satellite accounts to understand activities in subsistence economy taking place outside the market (Antonopoulos and Hirway, 2009).

Finally coming to the more general analysis of time use (considering both the hours inside and outside the market) we can find another type of concern justifying the accounting of human time: the quality of life of the people to which the time refers to. Some of the pioneers as Frederic Leplay started analyzing family budgets in a descriptive way around the mid of the nineteenth century, others as Eduard Engels focus on regularities of housekeeping statistics for explaining standards of living, but both just focusing on some activities (Szalai, 1966a). Other scholars have put the focus on racial division of paid and unpaid reproductive labor, analyzing the so-called double subordination due to gender and race discrimination (Glenn, 1992). Then, one of the first time budget studies in 1924 provides an analysis of daily life of workers in Moscow by S.G. Strumilin, a member of the Soviet economic planning office (Szalai, 1966a). Such study considered not only "productive work" (both for the community and private), but also other categories such as "housework" (e.g. preparation of meals or care of children), "lost time" (transport or shopping, which reflects an utilitarian conception of human activity), "indispensables necessities" (meals on the job and at home, sleeping) and other categories considered as "time at own disposal" including study and individual cultural activities, recreation and entertainment - for details see (Szalai, 1966a). Many other analyses have been performed afterwards in this line, but the multinational comparative time budget research project lead by Alexander Szalai in mid-1960s is considered a turning point in systemic standardization of time use surveys making possible cross-national comparison analyses. The nature of this analysis permitted to address not only living conditions, but also a detailed description of leisure activities as exposure to the principal mass communication media as radio, television or reading and other outdoor activities. Main activities considered in the accounting of time were: physiological needs, free time, household obligations, commuting time and trade or profession, which were analyzed in different days of the week, by sex, civil status, level of urbanization and industrialization, or rural vs urban (Szalai, 1966b).

A comprehensive analysis of time uses in historical series allows the study of how societal, economic, environmental or cultural aspects are interrelated. In fact, changes in the pattern of activities developed by a society associated with changes in human time use provide a valuable information to study causality in historical events. Analysis based on changes of human time allocation in societal activities is common in historians when describing past events or their sequence. For example, the dramatic reduction of the fraction of the work force employed in agriculture is a typical indicator used for characterizing the industrial revolution, one of the mayor historical changes in human history. Cipolla analyzes and uses the proportion of active population employed in agriculture as a key proxy of the level of industrialization of societies between 1750 and 1950: more than 40% in agriculture at the beginning of industrial revolution, between 21-40% during it expansion, and less than 20% during its consolidation (Cipolla, 1978).

All these approaches to the quantification of human time allocation are focusing on specific functional compartments of the society – how human time is used in a typology of production process, or how human time is used in a typology of household – or as an observable attribute of a given society – when relations over quantities of human time are used as indicators. There is no attempt to generate a holistic vision of how the profile of human time allocation inside the various compartments constraints the whole and vice versa. All these approaches are mono-scale.

3. The profile of human time allocation across levels as an emergent property associated with the expression of the metabolic pattern of society

3.1 The epistemological challenge of complexity in the analysis of the metabolic pattern of a society

In the previous section we saw that apart from the field of economics, human time allocation in society has been studied in many scientific disciplines from different angles: labor organization (Taylor, 1911), geography (Carlstein, 1981; Harvey, 1996), urban planning (Meier, 1959), just to name a few. Observations and quantitative results generated in these different disciplines belong to non-equivalent descriptive domains (Giampietro et al., 2006b, 2006a) and cannot be easily integrated into a common ‘model’ of analysis.

In this paper we provide a different take on the analysis of the profile of allocation of human time, a logic of analysis based on the concept of the metabolic pattern of social-ecological systems (Giampietro et al., 2012). This different logic combines in a holistic vision the various human activities entangled inside the various levels of organization of a society in a complex process of “production” and “consumption” of different types of inputs and outputs. This approach is more related to the framing adopted in sociology about human time allocation (Bailey, 1990; Bourdieu, 1977; Labanca, 2017; Schatzki, 2010, 1996; Shove, 2009; Shove et al., 2012; Wright, 2005) A society “produces and consume” different types of inputs: people, ideas, technology, food, energy carriers, institutions. Some of these things are material (observable object), others are not material (notional object). When expressing a given metabolic pattern some of the metabolic elements are consumed (flow elements such as energy carriers, food, consumable goods) whereas some other elements are not consumed (fund elements such as people, durable goods, infrastructures) (Georgescu-Roegen, 1971; Giampietro et al., 2012). The fund elements are not consumed but must be maintained and replaced. All metabolic activities of production, consumption, reproduction and maintenance require an inflow of inputs (energy and matter) and generate waste and emissions. In a metabolic pattern the various constituent components are all “producing” outputs (either useful or useless) and “consuming” inputs (Giampietro, 2018). In the metabolic view human societies can be seen as autopoietic systems (Maturana and Varela, 1985) in which the economic process is just one of many mechanisms of control required for the stabilization of the metabolic pattern – the expression of functions and the reproduction of structural elements. In this view, we can identify two sets of constraints affecting the possible profile of allocation of human time in modern society: (i) biophysical constraints determined by the structural elements composing the society (e.g. the quantity and the profile of types of individuals determined by demographic variables); and (ii) economic constraints determined by the functional elements of the economy (e.g. the quantity and the profile of types of job supply determined by the structure of the economy). On the top of these two set of constraints there is a third layer determined by the institutions and social norms determining social roles and social practices (Schatzki, 2010, 1996; Shove, 2009; Shove et al., 2012).

3.2 Moving from the level of analysis of individual to the level of analysis of the whole socio-economic system seen as a “bio-social organism”

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The idea of an economic opportunity cost of human time allocation: “time is money” (Franklin, 1748) or “time is a scarce resource” (Soule, 1955; Fischer, 2001) has been important in economic narratives. In this narrative a central problem for a rational agent is how to decide its optimal allocation. This idea has been elaborated in economic theory through the concept of labor as a limiting production factor, like capital and land. The same approach has been applied to the time needed to consume goods and services in order to maximize the level of welfare, by introducing the “household production function” (Becker, 1965; Lancaster, 1966). However, the two analysis of the two production functions (in a production process and at the household levels) remained boxed at a local scale of analysis. Outside economics we can find alternative narratives about human time allocation widening the perspective from the individual point of view to the social one – e.g. Gershuny (1989) uses time analysis as what he calls a new technique for studying long term social and economic structural changes.

Indeed, as early as 1941, in his seminal book “National Unity and Disunity: The Nation as a Bio-social Organism” George K. Zipf analyzed the concept of opportunity cost of time allocation, not assessed at the local level of individual households of industries, but at the level of the whole society. He suggested to consider the various socio-economic activities as contributing to the “emergent property” of a bio-social organism – the whole society. Reflecting on the roots of the Great Depression that hit the USA from 1929-1939, Zipf associated the onset of the economic crisis with the saturation of the ‘consumptive capacity’ of the US society. For the US economy to continue growing, its existing economic structure had to give way to a radically new one in which many more hours could be allocated to consumption. “… in 1929 the United States discovered a new "raw material": leisure time, which in a way is just as much a "raw material" as coal, oil, steel or any-thing else, because for many types of human activity, leisure time is an essential prerequisite... any change in kind or amount of goods or of processes within a social-economy will necessitate a restriation within a social-economy itself" (Zipf, 1941, p. 324). With the term restriation, Zipf intended a different pattern of allocation of human activity, matter and energy flows, that is, using a modern vocabulary a new combination of social practices across different levels of organization. His intuition is essential for understanding the analysis we propose in this paper.

The key point of multi-scale analysis is that the importance of the “opportunity cost” of human time is felt simultaneously by different “agents” expected to express a specific set of functions, across different hierarchical levels— individuals have a limited budget of time, households have a limited budget of time, economic sectors and whole societies have a limited budget of time. However, these constraints can only be observed by adopting different time scales. Because of their specific multi-scale organization complex systems generate contingency realities depending on the compromise solutions given by two opposite forces: (1) downward causation – determined by decisions taken at a higher level of organization that are affecting the option space of lower level agents – e.g. a change in working time decided by a factory affecting the workers, or the decide to de-industrialize the economy moving the production of manufactured goods abroad affecting the local employment; or (2) upward causation - determined by decisions taken at a lower level of organization that are affecting the option space of higher level agents – e.g. a successful strike of the workers forcing the factory to change an existing regulation, a dramatic change in policy in a given country due to a massive victory of the opposition party. In complexity theory this situation is described using the concept of double asymmetry in relation to the stabilization of hierarchical systems (Grene 1969). “The concept of double asymmetry indicates the peculiar status of each element of a self-entailing hierarchy that is operating in complex time, which is at the same time ruler and ruled. That is, the existence of a double asymmetry implies that the stability of each level depends on other levels either higher or lower in the hierarchy. The number of predators affects the number of prey and vice versa; governments determine the fate of citizens and vice versa". (Giampietro, 2003 – Chapter 6).

Within the given possible disposable time, when operating in an autopoietic hierarchy, an individual may choose to allocate his leisure time to either going to the movies (consuming a service) or a walk in the neighborhood. The contingency space entail that an individual may choose between "working more hours to increase the money available to be spent in less leisure time" or "working less hours to increase leisure time for which there will be less money to spend". This choice will affect the equilibrium between downward and upward causation. The more we move up in the hierarchy of levels of the society, the larger becomes the number of factors to consider for studying the overall pattern of human time allocation (Giampietro et al. 2012). In fact, more types of constraints affecting the definition of upward and downward causation have to be considered. In this work, we argue that the issue of human time allocation in societal organization is complex and it requires a more profound study than a mere analysis of efficiency of production factors or the representation of predictable rational behaviors of consumers. What people do in their life do not depend just on their "attitudes, behavior or choices" (Shove, 2010), but also on the social structure, the practices and the material arrangements developed throughout the history of the specific society considered (Schatzki, 2011). A metabolic approach avoids the trap of considering one topic at a time looking at processes using a single scale of analysis at the time. Adopting a societal metabolism framework, we can view a society as an integrated combination of social practices, expressed simultaneously across different levels of organization and observable only using different analytical framework addressing different aspects of societal life. The metabolic approach provides a framing that tracks the linkage across factors (characteristics of either structural or functional elements) through different levels and dimensions of analysis. The entanglement is determined by the relational organization among the parts and the whole that depends on a series of different types of controls both inside the society (economic, technical, institutional, cultural, political) and external to the society (availability of resources, environmental conditions, terms of trade determined by process outside the control of the given society).

4. How to quantify the constraints affecting the profile of human time allocation within the metabolic pattern of society

4.1 The constraints affecting the distribution of human time within the metabolic pattern

Evolutionary studies point at the existence of a general tendency expressed by complex adaptive system forced to be competitive by natural selection. They tend to maximize their own rate of production and consumption of resources in order to be able to express more functions (more adaptability) and operate at a larger scale (robustness): this is known as the Maximum Power Principle (Lotka, 1922; Odum and Pinkerton, 1955; Odum, 1994; Hall, 1995). Obviously, as explained by Zipf, in order to be able to consume more at the level of the whole they have to learn how to produce better inside the specific compartments dedicated to it. Hence, there is a systemic conflict inside evolving system (horizontal and vertical) across the functional elements of the metabolic pattern organized in holarchies* (Koestler, 1968; 1978; 1985) – * holarchies are systems organized

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by a process of coarse graining determined by the integration of upward and downward causations. This internal tension requires a continuous re-discussion of existing power relations (Grene, 1969; Iberall et al. 1981, Giampietro, 2003) about who decides the allocation of limited resources across competing demands: (i) horizontally, how to split the budget of time at the same level – an individual or a household having to do "too many things" at the same time; (ii) vertically, how to split the budget across levels – across different levels of actions. For example, more human time in the dissipative compartment (activities in household and services), implies less human time available in primary sectors (e.g. activities in agriculture and energy and mining). In social science this tension between the need of improving efficiency and the need of preserving diversity (adaptability) is reflected in the tension between Luhmann's theory of autopoiesis (Luhmann, 1995) where functionalism (the identification and reproduction of effective functional types) is see as a required solution for boosting efficiency, and Habermas theory of communicative action (Habermas, 1985) where a permanent re-negotiation of roles is required to preserve adaptability by continuously adjusting the goals of different social actors on the basis of a shared understanding of the sustainability predicament.

This discussion is important because social roles are mapping onto "typologies of human activities" and therefore they are defined above the individual level of analysis. The definition of roles is taking place above the level of individuals – it is an effect of the downward causation - as it is shown by the fact that their existence is independent from the specific instances: the incumbents in a given job is playing a working role that it independent on their presence (Bailey, 1990). In evolutionary terms, increasing the time allocated to both leisure and services has an important effect on the adaptability of society because it enhances diversity in the set of human activities that can be expressed by society (Giampietro et al. 2012). On the contrary, labor roles due to organization can be seen as replicated actions (Bailey 1990, p. 179) and therefore reflect what happened in the past. Also leisure time tends to be allocated over an 'established' set of leisure roles as individual choices are constrained by cultural identity. However, fidelity to leisure roles is less strictly enforced by society than that of labor roles. Moreover, the expansion of the demand of new services generated by the expansion of the activity in final consumption is a powerful driver for the creation of new labor roles in the service sector. In relation to this point, Meier (writing in 1959!) suggests that the analysis of changes could be used as indicator of economic growth: "Thus, if it can be shown that more people are choosing to use their time for a wider range of activities, one has as significant an indicator of socioeconomic growth as increased per capita income . . . A steady growth of per capita income over the long run does imply wider choice in time allocation: and the inverse is equally true". (Meier, 1959 p. 29).

In conclusion, we can say that any 'state' associated with a particular metabolic pattern of society represents a special solution to the problem of how to stabilize a dynamic budget of time and resources that must be shared among complementary but competing activities aimed at different purposes and carried out simultaneously across different levels of organization. Yet all these activities are contributing to a common emergent property (the reproduction of society). An output observable only at a larger hierarchical level of analysis. For this reason, it is important to understand the complexity of the interactions across level that the metabolic pattern implies. For example, any change done in the existing set of activities will have effect not only on the economy or the quality of life, but also on the environment. For example, a choice done at the level of the household - using plastic cutlery plastic and paper towels – to save time within the household, can generate, when scaled up across many households – upward causation – a problem of solid waste management. In this example an opposing downward causation - the definition of admissible social practices – could be used to influence the individual choices across the population of households. This analysis flags the complexity of factors to be considered for understanding the metabolic pattern. We need to start with: (i) a structural analysis of what is determining the typologies of individuals in the society – i.e. demographic factors; (ii) a functional analysis of what is determining the typologies of jobs in the society – i.e. the structure of the economy; (iii) an analysis of the process of coarse graining determining the formation of typologies of households found in a society and the profile of distribution of the population of households over this set. This is to say that individuals belonging to different typologies of households are expected to allocate their disposable time in different profiles of activities. However, in spite of their freedom of choice, they will have to respect structural constraints (they will be affected by their demographic characteristics) and functional constraints (they will be affected by their socio-economic characteristics). An overview of the set of relations over the categories of accounting of human activity and the quantity of time that can be allocated to them according to these two sets of constraints is given in Fig. 1.

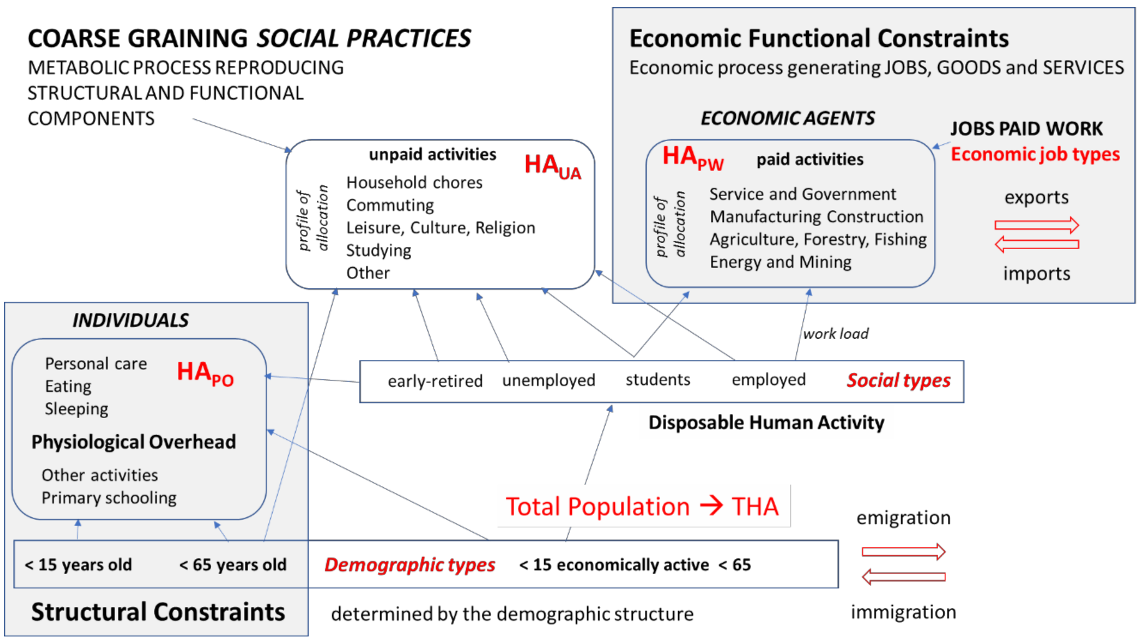

Fig. 1 Quantities of Human Activity: HA_{PO} (physiological overhead); HA_{PW} (paid work jobs); HA_{UA} (unpaid activities), affected in different ways by different types of constraints

The demographic structure determines a profile of distribution of persons over a given set of types – i.e. age classes (the division by gender can be used to increase the diversity of this information). The availability of types of persons included in the economically active population represents a type of structural constraints that cannot be changed with a re-adjustment of social practice in the short term. This constraint can be quantified measuring the given amount of human activities – HA_{PO} to be considered as a Physiological Overhead – obtained by summing together the hours of sleeping, eating, personal care and all the activities of people too young and too old to contribute to the stabilization of the metabolic pattern. This is a quantity of human activity that the society has to invest for the reproduction of its primary structural elements (the people), but that cannot be used for expressing other functions. Put it in another way, HA_{PO} reduces the disposable human activity in the society. In relation to this point we can see that social norms still affect the definition of economically active population (setting the age limits for entering and leaving the work force and defining the criteria to be used to

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characterize people not fit for working). In relation to this structural constraint, at a given in point in time the demographic structure of the society defines a certain quantity of disposable human activity that can be allocated between: (i) paid activities – HA_{PW} - jobs in the Paid Work sector; and (ii) unpaid activities – HA_{UA} including the remaining activities expressed in the society.

4.2 The choice of categories of accounting to assess the effect of constraints

The condition of closure over the three quantities of human activity illustrated in Fig 1 can be written as:
THA (Total Human Activity) = HAPO + HAPW + HAUA;

$$\frac{HA_{PO} + HA_{PW} + HA_{UA}}{Population} = THA_{pc} = HA_{PO}p.c. + HA_{PW}p.c + HA_{UA}p.c.$$

When expressed in actual hours of human activity in the society or expressed in terms of per capita hours of human activity:

4.2.1 Analysis of the demographic constraint - HAPO

At the level of individuals, the quantity of human activity available per capita is given:

$$THA_{pc} = 24\frac{h}{day} * 365\frac{days}{year} = 8760\ h/year$$

And this fact allows an easy conversion of the absolute values of Human Activity to per capita values over any chosen category of accounting:

$$THA\ = THA_{pc} * population \qquad HA_i = HA_i\ p.c.\ *population$$

At this point we can define the categories to be used to account quantities of human activities in relation to the structural constraint (demographic structure) on the basis of the definition of 3 types of individuals providing closure (mutually exclusive):

(1) <15 years old; (2) >15 economically active < 65; (3) >65 years old.

This demographic constraint entails that the whole human activity of the individual belonging to the first and the third category goes directly in HAPO, and a large fraction of the remaining human activity of the economically active population also is allocated in HAPO, depending on other factors and constraints.

4.2.2 Analysis of the economic constraint - HA_{PW}

The PW sector can be divided in 4 components as done by national statistics:

1. Agriculture, Forestry and Fisheries (AFF);

2. Energy & Mining (EM):
3. Manufacturing & Construction (MC);
4. Service & Government (SG);

Time allocation to economic functional categories (jobs in the Paid Work sector) can be obtained by labor statistics. Also in this case, the definitions of the four compartments provides closure (the sum of the size of the parts equals the size of the total) and it is mutually exclusive (no double counting). Total hours in the Paid Work (PW) sector can be obtained by summing those of the Paid Work in the composing sectors:

$$HA_{PW} = HA_{EM} + HA_{AFF} + HA_{SG} + HA_{MC}$$

As illustrated earlier, the same relation can be expressed on per capita basis. Moreover, another way of calculating these quantity (adding redundancy to the accounting by diversifying the sources of data) is to multiply the number of employed workers per type of employment in the various (sub)sectors by the corresponding workloads (expressed in hours per year).

4.2.3 *Closing the accounting of human activity by adding more categories – HA_{UA}*

Time use survey use sets of categories of accounting of human activities providing closure. For example, the “Harmonized European Time Use Survey”, 2008 Guidelines (based on earlier experience with the Multinational Comparative Time-Budget Research Project (Szalai, 1972), which is the European methodological reference for time use surveys adopted the following categories: Personal Care; Employment; Study; Household & Family Care; Voluntary Work & Meetings; Social Life & Entertainment; Sports & Outdoor Activities; Hobbies & Computing; Mass Media; and Travel & Uspecified Time Use (left column in Table 1).
In our study we adopt a reduced set of categories (see right column in Table 1). In fact, Voluntary Work & Meetings; Social Life & Entertainment; Sports &Outdoor Activities; Hobbies & Computing; and Mass Media are considered in the literature of social science dealing with time use as “expressive activities” (Pentland et al., 2002) and refer to activities that people choose during their free time and that are not related to productive or maintenance chores. We grouped these activities in the category Leisure, Culture & Religion and for this reason we use only 6 categories of accounting for human time.

Table 1 Correspondence between HETUS categories and selected human time categories used in the analysis.

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HETUS Categories	Selected human time Categories
Personal care	Physiological Overhead
Paid work	Paid work
Study	Study
Household chores & Family Care	Household chores & Family Care
Voluntary Work & Meetings	Leisure, Culture & Religion
Social Life & Entertainment	
Sports & Outdoor Activities	
Hobbies & Computing	
Mass Media	
Travel and Unspecified Time Use	Commuting & Unspecified time

5. Quantitative results illustrating the effect of the constraints across levels

5.1 An international comparison of the profile of allocation of human time in EU countries and in China

We present below a comparison of the profile of human activity, at the level of the whole society for: (i)12 EU countries (Spain, Greece, Bulgaria, Italy, France, Sweden, UK, Finland, Czech Republic, Romania, Netherlands, Germany) chosen for the diversity of their economy and geographic location; (ii) their average labelled "EU12"; and (iii) China.

Table 2 Characterization of the profile of human allocation at the level of the whole society for 12 EU countries, their average value E12 and China – referring to the year 2012

	Time in Households	Time in Paid Work	Dependency ratio	Child dependency ratio	Aged dependency ratio	unemployment	Hours in PW per worker per year	Hours in PW per capita per year	Population (millions)
Spain	92%	8%	48%	22%	26%	25%	1785	665	47
Greece	91%	9%	52%	22%	30%	25%	2321	740	11
Bulgaria	91%	9%	48%	20%	28%	12%	1952	773	7.3
Italy	92%	8%	54%	22%	32%	11%	1939	719	60
France	93%	7%	56%	29%	27%	9.8%	1636	658	64
Sweden	91%	9%	55%	26%	29%	8.0%	1661	785	9.5
UK	91%	9%	52%	27%	26%	7.9%	1718	766	64
Finland	91%	9%	53%	25%	28%	7.7%	1723	774	5.4
Czech Repu	90%	10%	45%	21%	23%	7.0%	1870	849	11
Romania	90%	9%	47%	23%	24%	6.8%	1905	775	20
Netherland	91%	9%	51%	26%	24%	5.8%	1531	745	17
Germany	92%	8%	52%	20%	31%	5.4%	1509	713	81
China	85%	15%	36%	24%	12%	4.1%	2196	1244	1354
Average EU	91%	9%	52%	24%	28%	11%	1714	721	397

European data are from: https://ec.europa.eu/eurostat/data/database. Chinese data are from the: Census of the People's Republic of China; China Statistical Yearbook; China Labour Statistical yearbook; China Energy

Statistical Yearbook.

In Table 2 we can observe that the value of the ratio "time outside Paid Work"/"time inside Paid Work" is clearly different in China compared with the rest of EU countries. This difference can be easily explained by the low value of dependency ratio in China – 36% - determined by a low life expectancy (only 12% of aged dependency ratio). As a curiosity, one can notice that France the EU country with the highest dependency ratio – 56% - and the lowest amount of time in paid work –with 7% of the total or 658 hours per capita – is actively involved in a political debate about a reduction of the workload per year in the paid work sector.

Other studies based on the application of MuSIASEM confirm the generality of these finding. Outside Europe the fraction of hours of time in the paid work sector (the formal economy) is similar – for example in 1980 and 2000 Brazil had 9.3% and 11.3%, Chile 7.8% and 9.9%, and Venezuela 7.3% and 9.9% respectively (Eisenmenger et al., 2007). Velasco et al (2015) found that in India between 1990 and 2010 this value was around 10%. Similar values have been found in Australia 9– 10%, Canada 8–9.5% and U.S. around 10% in 1990 and 2008 (Chinbuah, 2010). Other EU countries not included in our sample have similar values of those reported in Tab. 2. For example, Bulgaria and Hungary with 7–8%, Poland with 8–9% (Iorgulescu and Polimeni, 2009). The low dependency ration in China (36%) can provide an important temporal economic advantage in relation to aged countries like France (56%), Sweeden (55%), Italy (54%) or Finland (53%). The dependency ratio can depend on a small fraction of youths, or elderly, or both. In the example illustrated in Tab. 2, EU12 and China have the same low child dependency ratios (24%), but they differ in terms of age dependency ratio. In relation to this point, it should be noted that an aged society has an additional burden on the economy, the smaller fraction of the economically active population has to provide an important quantity of services to the dependent elderly.

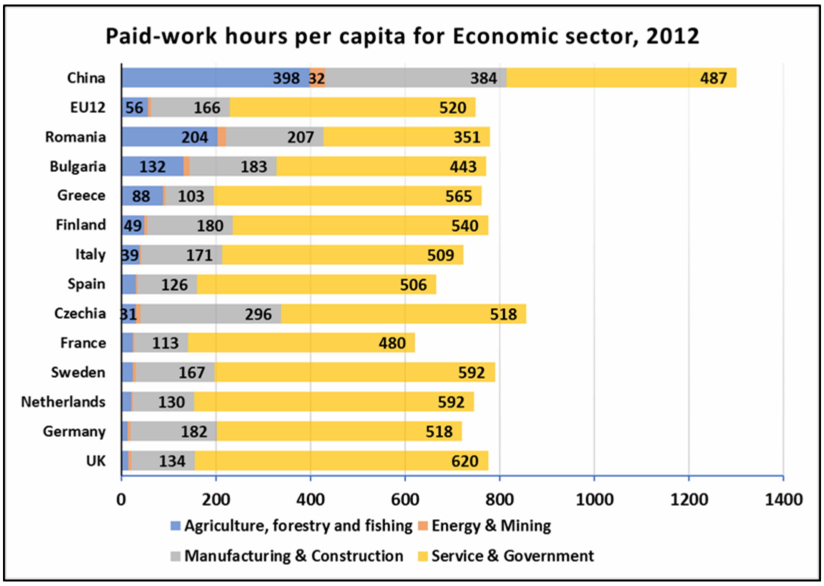

Fig. 2 The break-down of hours in the Paid Work sector per capita per year

The profile of distribution of hours in the paid work sector, shown in Fig. 2, is measured in "per capita per year in the society". We use this proxy (hours in PW per capita per year) for measuring the profile of investment of hours in the Paid Work sector in order to compare countries with a different size of their total population. The figure clearly shows that the service sectors in Europe is using the majority of the available working time in the

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Paid Work sector. The comparison with China, illustrated in a different way in Fig. 3, is impressive: China uses more than 1,300 hours per capita per year in Paid Work compared with less than 750 hours per capita per year used in PW per capita. However, in spite of this difference, almost all the EU countries have a much larger number of hours per capita per year in the Service sector. This observation can be used to generate another indicator that can be associated with the level of economic development of a country (proposed as the level of Bio-Economic Pressure in the MuSIASEM approach (Giampietro et al., 2012)). The more developed is a society the larger is the investment of human time outside the Paid Work and the larger is the investment of hours inside the Paid Work in the service sector - versus the hours invested in the primary sectors of the economy (Agriculture and Energy and Mining). In the jargon of the metabolic analysis, the primary sectors can be seen as the sectors degrading natural gradients provided by nature to generate the inputs required (food, energy, material) to the rest of the society. For this reason, the two primary sectors are called "catabolic sectors" – opposite to the "anabolic sectors" of the society -i.e. secondary, tertiary and household sectors.

	Catabolic Sectors (primary sectors)				
	Agriculture, forestry & fishing	Energy & Mining	Manufacturing & Construction	Service & Government	Ratio SG/ catabolic sectors
UK	15	6.4	134	620	30
Germany	14	6.0	182	518	26
Netherlands	22	3.1	130	592	24
Sweden	24	7.1	167	592	19
France	24	3.4	113	480	17
Czechia	31	11	296	518	15
Spain	31	3.5	126	506	13
Italy	39	3.5	171	509	12
Finland	49	6.1	180	540	10
Greece	88	5.5	103	565	6.0
Bulgaria	132	13	183	443	3.1
Romania	204	17	207	351	1.6
EU12	56	7.1	166	520	8.2
China	398	32	384	487	1.1

Fig. 3 Profile of distribution of hours inside the paid work sector

When using as indicator "Ratio SG/catabolic sector" in relation to hours of human activity in the PW sector, we can focus more specifically on differences due to gradients in economic development rather than in demographic structure.

5.2 An example of coarse-graining of human activity for Spain

Next example of quantitative analysis of the allocation of human time across levels is based on data referring to Spain. Data source: Spanish Time Survey 2009-2010 (Instituto Nacional de Estadistica (INE, 2011). INE data are consistent with the methodology of reference in Europe and amenable to the categories of accounting listed above (Time Use Survey 2009-2010 Methodology, July 2011, INE).

We go back, now, to the distinction between two types of constraints: (i) a set of structural constraints given by the actual demographic structure – i.e. the types of individuals found in the society and the profile of allocation of instances of these types in the actual population; (ii) a set of functional constraints given by the actual economic structure – i.e. the types of jobs found in the different economic sectors and the profile of allocation of instances of employee in these jobs among the economically active population. As illustrated in Fig. 1 the combination of these two constraints will define the overall profile of allocation of time in the society. Data describing the profile of allocation of human activity in relation to these two types of constraints in Spain in the year 2009-2010 is given in Fig. 4.

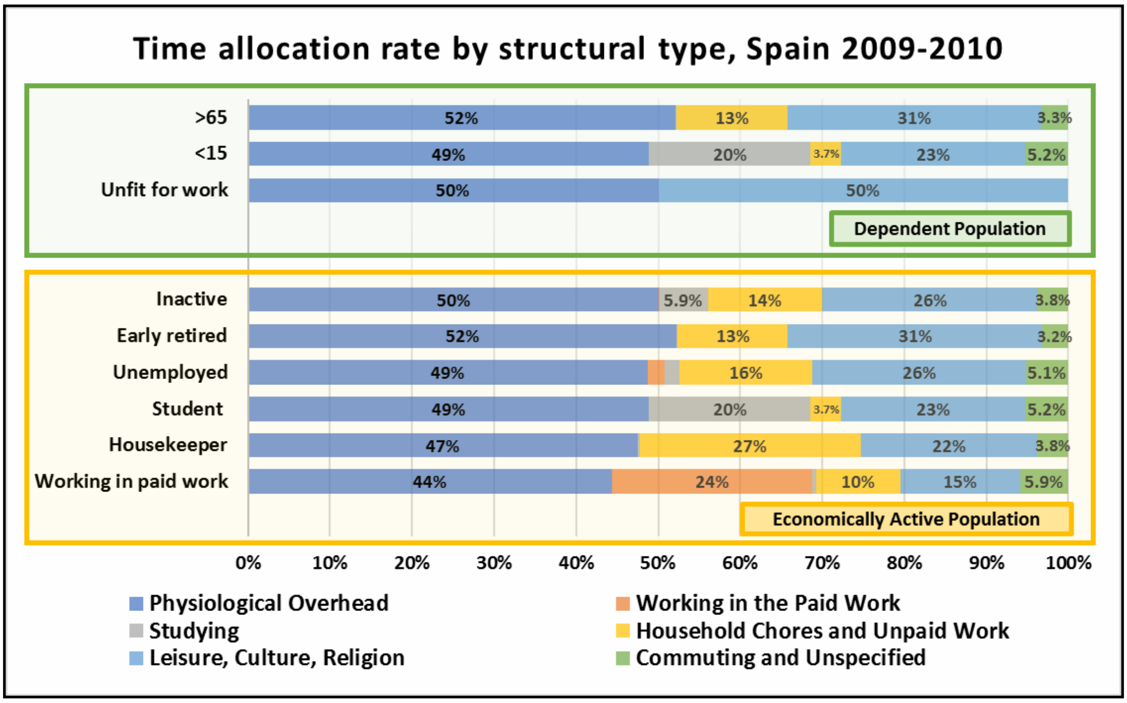

Fig. 4 Profile of time allocation in Dependent Population and Economically Active Population

In relation to the profile of human time allocation inside Paid Work we can break-down the profile of allocation in relation to 4 social roles determined by a 2x2 matrix: (i) Male vs Female employee and (ii) Full time vs Part time employee. This information is given in Fig. 5.

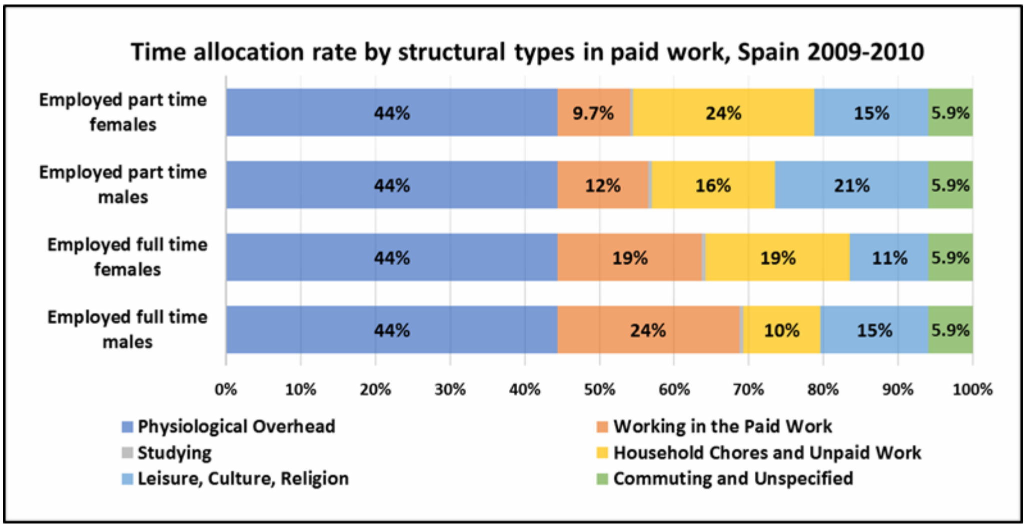

Fig. 5 Profile of time allocation in type of individuals in the Economically Active Population

By combining the information coming from the two figures, we can visualize the entanglement over the various quantities of human time allocated across the various categories of accounting of human activity – Fig. 6.

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Spain 2012	Profile of social roles (% total population)											
	Employed Full Time Males	Employed Part Time Males	Employed Full Time Females	Employed Part Time Females	Unemployed	Student	Early Retired	Others	Unfit for work	<15	>65	Population (millions)
	19%	1.4%	13%	4.0%	12%	7.7%	1.0%	6.1%	2.5%	15%	17%	47
Profile of activities	**Hours per capita per year by Structural type**											**Total hours per activity**
Physiological overhead	747	53	508	157	531	331	45	268	109	650	796	4193
Household Chores & Family Care	174	18	216	86	177	25	12	75	0	49	206	1037
Paid work	411	15	222	34	0	0	0	0	0	0	0	681
Study	8.1	0.58	5.5	1.7	42	133	0	32	0	261	1.4	486
Leisure, Culture, Religion	245	25	120	54	284	152	26	140	109	299	472	1927
Commuting & Unspecified	99	7.0	68	21	56	35	2.7	20	0	69	51	429
Total hours per social role	1685	118	1139	354	1089	676	85	534	217	1328	1526	

Fig. 6 The entanglement of the profile of allocation of human time across categories of human activity and across a given set of social roles

The set of relations identified in Fig. 6 can be used to study the viability of the dynamic equilibrium in the metabolic pattern as illustrated in the next section.

5.3 The implication of the existence of dynamic equilibrium over time use in society: the matching of the upward and downward causation

In order to contextualize and give meaning to the nature of the dynamic equilibrium between upward and downward causation of time allocation in Spain we have to look "at the big picture" – i.e. how all these quantities of human activity are functionally related within the society. An overview of the relations is given in Fig. 7 (data refer again to Spain 2012).

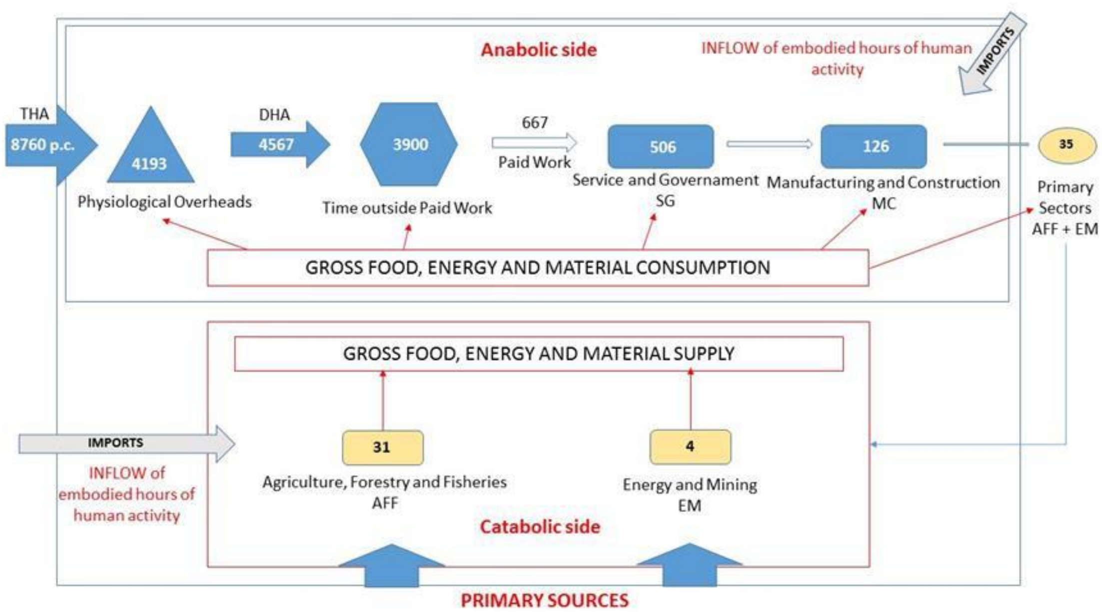

Fig. 7: The dynamic budget of time allocation at the societal level. Time allocation is expressed on a per capita basis. Data refer to Spain 2012.

We can go through the various numbers shown in Fig. 7 starting from the upper left corner. Starting with 8,760 hours per capita per year (24 hours/day x 365 days/year) we have a first quantity of human activity (HAPO) – the physiological overhead affected by the demographic structure that consumes (4,193 hours). This leaves out a quantity of Disposable Human Activity of 4,567 hours. A large part of this quantity of hours is used by the activities performed outside paid work (3900 hours). This leaves only 667 hours available for Paid Work (HAPW). This means that the share of the overall time budget (THA of 8760 h/yr) allocated to paid work is 7.6%. As observed earlier the majority of the hours in Paid Work are used by the Services and Government sector (506 hours) because of the social demand for health care, education, citizen protection, insurance, banking, and leisure related services. The sector of "manufacturing and construction" uses 126 hours (only 19% of HAPW or 1.4% of THA). Even more reduced is the amount of human time available for the two primary sectors (agriculture and energy and mining) that combined use 35 hours (5.2% of HAPW or 0.4% of THA).

When comparing these data with the data of China – Fig. 8 - we can explain the heavy reliance on imports of EU countries in relation to energy, minerals, manufactured products and food commodities (especially in the form of feed for animal production) (Velasco-Fernández et al., 2018). In fact, the solution of imports allows to compensate the shortage of investments of human time in the production of the required inputs consumed by the society (Velasco-Fernández et al., 2018). In conclusion, when considering the profile of human time allocation, we can conclude that favorable terms of trade translate into a net inflow of embodied human activity that would have to be invested in PW to produce the consumed goods, but that it is externalized to other countries. The same is true for the primary production sectors (Agriculture, Forestry and Fisheries and Energy and Mining), also in this case, there is a significant inflow of embodied hours of virtual work associated with the massive import of energy inputs and agricultural commodities, typical of EU countries (Velasco-Fernández et al., 2018).

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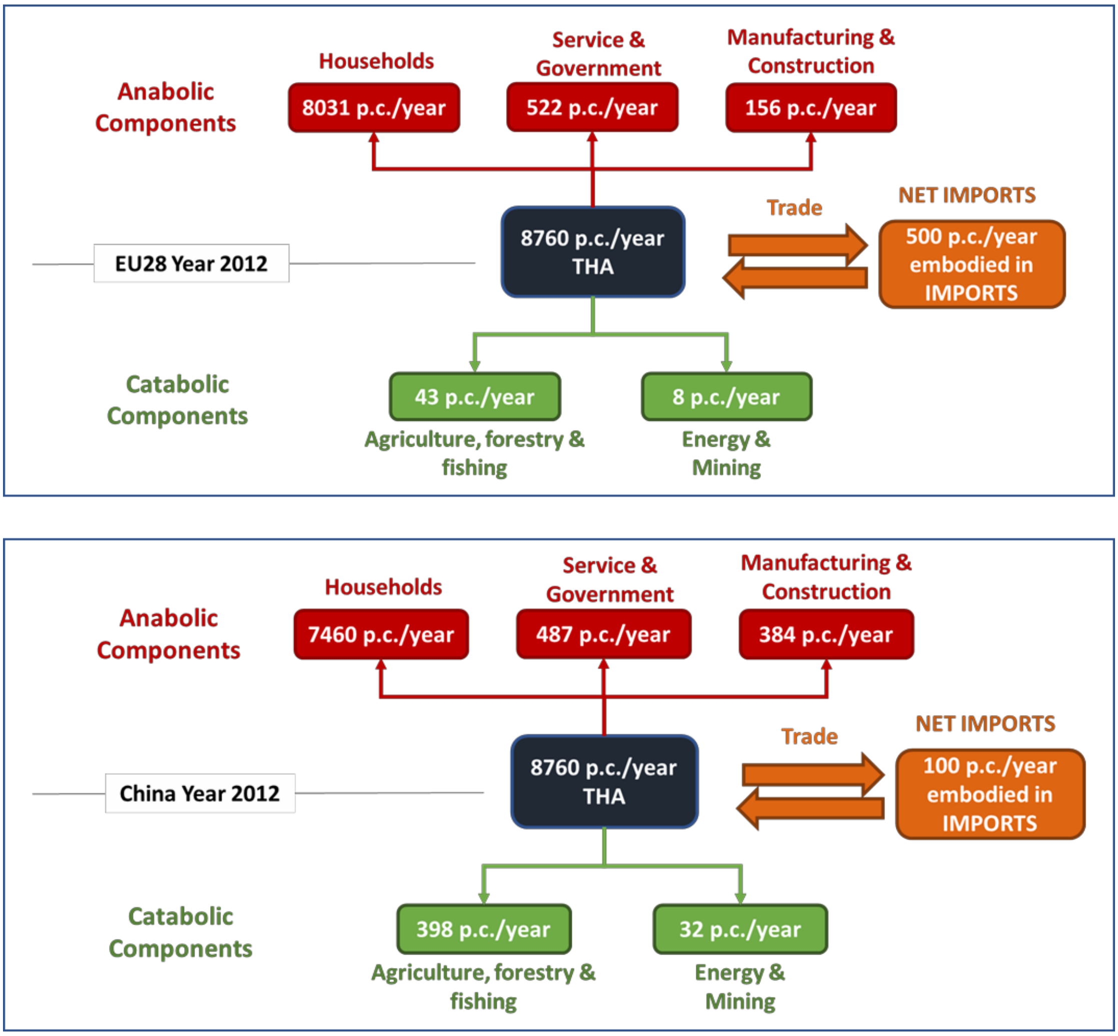

Fig. 8 A comparison of the dynamic equilibrium of human time allocation: EU and China Data from (Velasco-Fernández et al., 2018).

In the comparison illustrated in Fig. 8 (using a different set of data allowing the assessment of the embodied quantities of work in imports), we can see that: (i) the quantity of hours of productive human activity (allocated to Paid Work) in China is almost double that in Europe: 1,300 h p.c./year versus 749 h p.c./year on average; (ii) in spite of a much smaller quantity of hours in the Paid Work, Europe has more hours of work in the service sector than China: 520 h p.c./year versus 487 h p.c./year; (iii) this difference is explained by the bonus of 500 h p.c./year that the sample of EU28 receives in the form of (cheaply) paid work hours embodied in its imports(Velasco-Fernández et al., 2018). This bonus is essential for Europe's current lifestyle and standard of living.

6. Conclusion

Key factors determining the feasibility, viability and desirability of the metabolic pattern can only be observed by looking simultaneously at the demographic, social, economic, biophysical and political domains. To make things more challenging for the analyst, these factors affect each other in an impredicative way in shaping the profile of distribution of human activities in the society. The entanglement between downward causation (the institutional definition of functional elements and their expected relations) and upward causation (the structural constraints imposed by biophysical processes) generates a contingent option space in which different agents defined at different levels of organization – i.e. individuals, households, communities, economic agents, national states, international organizations – have to negotiate coarse graining solutions capable of sharing stress across the various structural elements expressing the metabolic pattern. This phenomenon can only be studied by acknowledging the existence of impredicative relations over factor that can only be established across representations belonging to different disciplinary domains. This means that we have to learn how to move to a new type of quantitative analysis based on "complex system thinking" and "transdisciplinarity". Only in this way, it becomes possible to integrate the various disciplinary knowledge available to get a better grip on the sustainability challenge.

Note that the analysis of time allocation pattern in this paper has been expressed in hours per capita per year. However, this analysis of the pattern remains valid also if the allocation of human activity is expressed in absolute terms (by multiplying the hours per capita per year by population size). In metabolic analysis it is important to always consider both qualitative and quantitative changes in the dynamic equilibrium. In fact, both changes in the overall size of the system (relevant in relation to scale sensitive issues, such as limited amount of resources) and in the internal re-allocation of inputs (affecting the relative size of the functional and structural elements) are equally important in determining the stability of the dynamic pattern.

Coming to the challenge of moving to a more sustainable pattern of production and consumption, the analysis of the metabolic pattern flags the key importance of considering the role played by human time allocation in determining feasible, viable and desirable solutions. Particularly concerning in relation to the goals of reducing the use of fossil energy and technology are the following points:

1. The continuously increasing expectations for better standard of living translate into:
   - a reduction of HA_{PW}/THA – i.e. a reduction of HA in the Paid Work sectors of the economy;
   - an increase of HA_{SG}/HA_{PW} – i.e. a reduction of HA in the productive sectors of the economy: a decreasing HA_{PS}/THA.

This change is due to the following drivers in the metabolic pattern:

- Long life expectancy and early retirement, translating into a relatively large inactive population;
- Long compulsory schooling, easy access to higher education, higher minimum age for admission to employment and abolishment of child labor, further reducing the economically active population;
- Availability of subsidies for the unemployed, who can afford to wait for a desirable job offer, resulting in longer periods of unemployment;
- Small work load per year (short work day, more vacations) reducing the actual supply of labor hours per employed person;
- More paid leaves (sick leave, study leave, maternity leave, paternity leave), further reducing the actual supply of labor hours.

Obviously, we all love this package of changes, but we have to be aware that these changes require a massive technical capitalization (more machines and a larger consumption of energy carriers) in the primary sectors as well as in the sector of manufacturing and construction. The alternative is to externalize to other economies the production of primary and secondary commodities.

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2. The existing pattern of economic development entails a standard evolution of the structure of the economy making more and more difficult to stabilize the dynamic equilibrium inside the metabolic pattern: (i) on one hand, the dramatic expansion of the relative size of the anabolic compartment composed by the household sector (in h/year per capita), the service and government sector inside the paid work sector – human activities in the paid work responsible for the welfare of the society (HA_{SG}) and the manufacturing and construction sector (HA_{SG}); (ii) on the other hand, a dramatic increase of the pressure on the catabolic compartment, in charge to produce the surplus of material, energy and food items while getting less and less human activity to be used for this task. In this way, society achieves an internal labor differentiation and specialization that better fulfills the needs (and desires) of its citizens for services. However, this configuration can only be realized if the labor productivity in the primary production sectors is sufficiently high. This is “the” factor to be considered to check the sustainability of a given pattern of production and consumption. In fact, at the moment such a high productivity is generally obtained through a massive reliance on technical capital powered by fossil energy and by imports (embodied human labor) obtained by externalizing the requirement of both resources and production factors to other social-ecological systems.

As history has shown, the profile of allocation of human activity inside human society is very flexible and responsive to changing political, economic and environmental contexts. In difficult situations (e.g., wartime, famine) children and elderly may be expected to contribute to paid work and the workload of the economically active population can be increased substantially. The level of acceptable consumption can be dramatically reduced and still human societies can survive and reproduce themselves. We do not expect that a quick move toward a sustainable pattern of production and consumption will generate the same disturbance on our life styles experienced in wartime, however, we not even expect that a radical transformative change in the society toward a progressive elimination of non-renewable resources from our daily consumption will be a walk in the park. This paper wants to illustrate that it would be wise to study more in detail how the profile of human time allocation is related to the ability to stabilize the metabolic pattern of society – i.e. how can we remain sustainable while enjoying a decent life.

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Tracking the pathway towards SDG12 in EU-28: the Consumption Footprint of countries

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Abstract

EU policy is pushing a transitional pathway towards a more sustainable Europe, with a transformed production and consumption as well as enhanced bio-economy and circular economy strategies. Such pathway is aimed at driving the EU to achieving the United Nations' Sustainable Development Goal (SDG) 12. In this context, the life cycle assessment (LCA)-based Consumption Footprint indicator was designed with the goal of accounting for the environmental impacts of consumption in the EU. This set of LCA-based indicators (also available as single, weighted, score) aimed to quantify the environmental impacts of apparent consumption in the EU. It was calculated as the sum of the domestic environmental impacts and of the impacts of trade (i.e., impacts of imports minus impacts of exports). While statistic data were collected to quantify the economic and mass flows taking place in the domestic territory, the trade inventory was based in two different approaches: 1) the Consumption Footprint bottom-up used process-based LCA to model the impacts associated with the most traded products to and from the EU, while 2) the Consumption Footprint top-down employed input-output based LCA, using Exiobase 3 (hybrid version) as the supporting database. The Environmental Footprint (EF2017) method was used for the impact assessment phase to assess diverse aspects of the environmental effects of consumption.

This paper assesses how the Consumption Footprint (CF) indicator addresses the SDGs from the goal to the indicator levels. To do so, the CF indicator was mapped to the different goals, targets and indicators of the SDGs framework with the goal of investigating the actual coverage of this LCA-based indicator, which was compared to the coverage of the Eurostat SDG indicators and the Planetary Boundaries (PBs). Primarily designed to monitor SDG12, the CF may address interlinkages with several SDGs. At the goal level, the CF indirectly considered socio-economic indicators, directly addressed SDG12 and the implications on SDGs 2, 3, 6, 7, 8, 9, 11, 13, 14 and 15. However, coverage was very limited at the target and indicator levels due to their specificity, even for SDG12. The CF can enable to address some SDG indicators and appears a relevant option to complement the existing framework of indicators. In particular, using this LCA-based indicator presents some advantages as compared to current SDG indicators: the quantification of the impacts rather than the pressures, the consumption- based approach that enables to account for the impacts along the life cycle of products and services consumed, the inclusion of trade-offs among environmental impacts and the possibility of calculating a weighted score. The CF covered the SDGs indicator similarly to the Eurostat SDGs indicator set and the PBs. The major limitation towards fully covering SDG indicators was the presence of indicators addressing policy implementation, national statistics or cooperation issues, which are out of the scope of the CF. To further enlarge the coverage, social LCA indicators and new developments in environmental impact assessment would enable to include some additional SDGs that are currently out of the scope of the CF.

Keywords: Sustainability, SDG12, Life Cycle Assessment, Environmental Impacts; Household Consumption

1. Introduction

The progress of humankind drives a reduced global environmental quality in such intensity that the Earth has entered a new geological era, the Anthropocene, where irreversible changes have been caused (Crutzen, 2002; Steffen et al., 2007). Towards enabling a sustainable pathway where humankind and environment are balanced, the United Nations developed the Sustainable Development Goals (SDGs) (UN, 2015). The SDGs include 17 goals addressing global challenges with specific targets that encompass aspects from food insecurity to water quality. This framework of targets and indicators allows for monitoring the regional or national performance in sustainability aspects. However, the direct implementation of the SDG scheme is limited due to lack of data or specific challenges of the geographical area under evaluation. For example, Eurostat has developed a set of indicators to monitor SDGs in the EU based on available statistics (Eurostat, 2019), while Allen et al. (2019) have discussed the need to integrate alternative and new indicators into the SDG scheme for assessing Australia.

Due to the relevance of consumption as a driver of environmental impacts, SDG12 focuses on responsible production and consumption as a pathway to reduce environmental degradation and improve resource efficiency in global lifestyles (UN, 2015). For this purpose, the EU has implemented policy that pushes a transition to a more sustainable Europe, including the promotion of a bio- and circular economy (EC, 2015; EC, 2019). With the aim of monitoring the progress towards SDG12, indicators that model the environmental impacts of consumption are essential. Studies with this goal are available in the literature, where the need of a consumption-based approach is highlighted, considering the impacts of trade beyond the domestic ones (Wood et al., 2018).

Within this context, Life Cycle Assessment (LCA), a standardized methodology for integrated impact assessment where the environmental burdens associated to the entire life cycle of products can be quantified (ISO, 2006), represents a potential method to quantify the environmental impacts of consumption while monitoring SDG12. As advantages, LCA is a comprehensive method that evaluates the impacts along supply chains and allows assessing diverse potential environmental impacts. Such approach can unveil potential trade-offs of environmental impacts between impact categories or life cycle stages of products (Sala et al., 2019b). Furthermore, LCA is a recommended method for supporting policy at the EU level as part of the toolbox of the Communication on Better regulation (CEC, 2015).

1.1. The Consumption Footprint indicator: the environmental impacts of EU consumption

In this context, the Consumption Footprint indicator (Sala et al., 2019a) is an LCA-based set of indicators designed to quantify the environmental impact of consumption at the country scale, thereby subtracting the environmental impacts embedded due to exports to the domestic impacts and adding the impacts embedded in imports. Following the LCA method, environmental pressures were collected in an inventory and later converted into environmental impacts by implementing an impact assessment method. Regarding the inventory, statistical data from multiple sources were compiled to quantify the domestic environmental flows

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within the EU territorial border (Sala et al., 2015). However, two approaches were considered for modelling the trade component (i.e., imports and exports): a bottom-up approach that employs process-based LCA (i.e., modelling specific products and upscaling their impact according to consumption patterns of product groups; Corrado et al., 2019) or a top-down approach based on input-output-based LCA (i.e., quantifying the burdens of trade by using environmentally-extended multi- regional input-output tables; Beylot et al., 2019).

Regarding the impact assessment, the 16 indicators of the Environmental Footprint reference package 2 method were employed (here reported as EF2017; Figure 1.a) (EC, 2013; EC-JRC, 2018; Fazio et al., 2018).

The goal of this set of indicators was to quantify the environmental impacts of EU consumption to address and model SDG12 (on responsible consumption and production) and partially SDG8 (target 8.4 on decoupling economic growth from environmental impacts), SDG9 (on industry, innovation and infrastructure) and SDG11 (on sustainable cities and communities) (Sala et al., 2019a). The modelled production and consumption patterns were evaluated in terms of implications on the different environmental impact categories of the EF2017 method, which were also related to other SDGs on human health and ecosystems quality (Figure 1.a). However, the authors linked SDGs and Consumption Footprint indicators at the goal level, rather than deeply assessing the targets and indicators of each goal.

Although results varied depending on the approach taken (Beylot et al., 2019), both top-down and bottom-up results indicated that economic growth showed decoupling from the environmental impacts resulting from EU consumption between 2005 and 2014 (Sanyé-Mengual et al., 2019) (Figure 1.b). The decreasing trend of the environmental impact was, however, larger for the bottom-up approach (-23%) than for the top-down (-0.2%). Although the positive results on trends, contrasting the average environmental impacts of consumption against the Planetary Boundaries (PBs) (Rockström et al., 2009; Steffen et al., 2015) highlighted that the impact in several categories was beyond the safe operating space for humanity (Figure 1.a) (Sala et al., 2019c). Therefore, the assessment of the environmental impacts of EU consumption indicated a relative sustainability with decreasing trends but still beyond some absolute sustainability thresholds. Moreover, indicators related to ecosystems quality (e.g., biodiversity loss) showed that there is a steady decline (IPBES, 2019), suggesting that decoupling of pressures is not enough.

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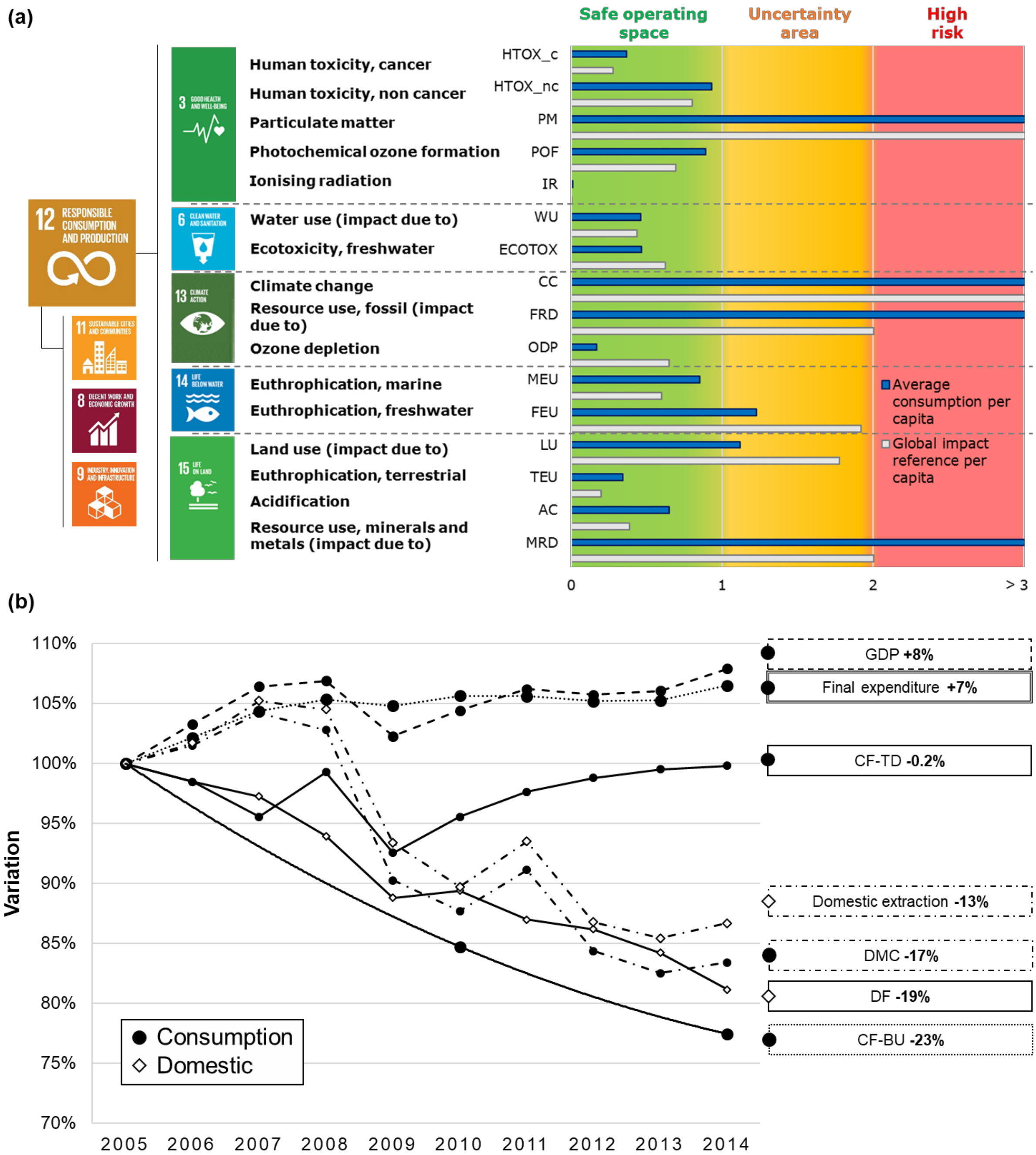

***Figure 1**. (a) Link between the different SDGs and the EF2017 indicators, based on Sala et al. (2019a), and results against the PBs for 2010 (adapted from Sala et al., 2019b); (b) Trend of the Consumption Footprint top-down (CF-TD), the Consumption Footprint bottom-up (CF-BU) and the Domestic Footprint (DF), compared with the Gross Domestic Product (GDP), Final expenditure, Domestic Material Consumption (DMC) and Domestic Extraction between 2005 and 2014 (based on Sanyé-Mengual et al., 2019).*

1.2. Goal and objectives

Notwithstanding the potential of the Consumption Footprint to monitor SDGs, the link between LCA and the SDGs framework has been identified as a challenge in promoting a life cycle perspective towards SDGs (Laurent et al., 2019; Sala et al., 2019a). Hence, this paper aims to analyse how LCA-based indicators can support the monitoring of SDGs, focusing on the Consumption Footprint indicator (developed for the EU) designed to address

SDG12. Towards exploring this link, the following objectives were pursued:

(a) to map the links between the Consumption Footprint indicator and the SDGs at the goal, target and indicator levels;

(b) to compare the coverage of the Consumption Footprint at the indicator level with Eurostat indicators used at the EU level to monitor SDGs progress;

(c) to evaluate the link with absolute sustainability targets, such as the PBs.

2. Methods

The core element of the analysis was the mapping process between UN SDGs and the Consumption Footprint indicator (Figure 2). This process started by assessing SDG12, as the goal directly addressed by the Consumption Footprint, and broadened to SDGs 8, 9 and 11. Then, the SDGs related to the EF2017 environmental impact indicators were evaluated. Finally, the remaining SDGs were analysed. Regarding the mapping process, this was done from goal to indicator levels. Regarding goal and target levels, the mapping aimed at identifying the existence, even if partial, of a link between the Consumption Footprint indicator and the SDGs. At the indicator level, the mapping aimed at identifying whether the CF indicator could be used as (or as a complement to) a SDG indicator (UN, 2013). At this level, the mapping included Eurostat SDGs indicators (Eurostat, 2019) and the PBs framework developed by Rockström et al. (2009), for comparison.

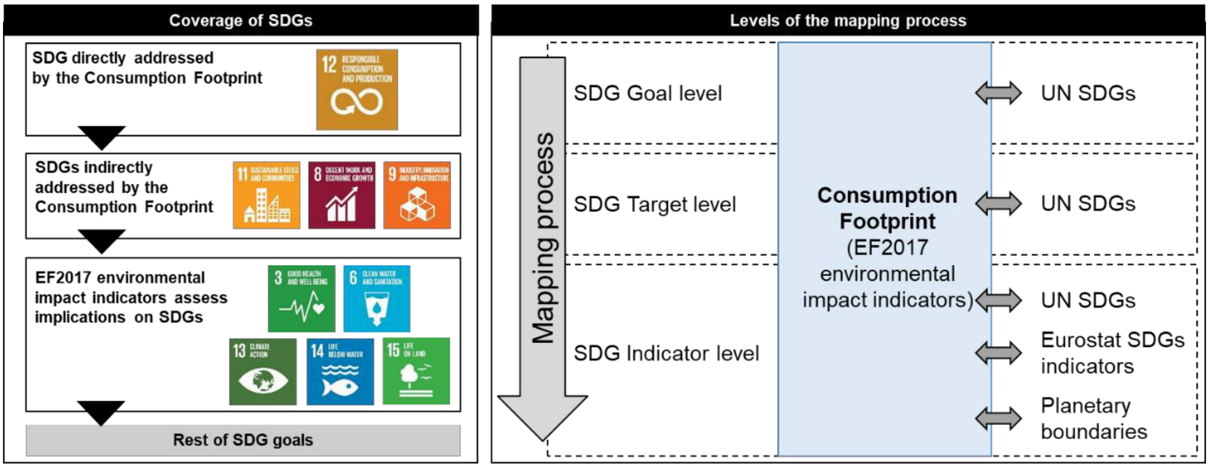

Figure 2. *Mapping process of this study between UN SDGs, the Consumption Footprint indicator, Eurostat SDGs indicators and the PBs: from goal to indicator level.*

A network analysis was applied to the mapping at the target level to observe trends in how SDGs relate to the Consumption Footprint indicator and midpoint impact categories of the EF2017 method. The network analysis was performed with the software Gephi 0.9.2 (Gephi Association, 2016) by applying the ForceAtlas 2 algorithm (Jacomy et al., 2014).

3. Results and Discussion

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This section details the results from the mapping between the Consumption Footprint and the SDGs at the goal, target and indicator levels. The mapping results are compared with the Eurostat indicators and the PBs. The advantages and limitations of the potential use of the Consumption Footprint to track SDGs are discussed.

3.1. Addressing SDGs at the goal level

Table 1 details the mapping between the Consumption Footprint indicator and the 17 SDGs, based on the mapping already performed by the authors of the indicator (Sala et al., 2019a). In line with the goal of the Consumption Footprint, the mapping results indicated that this indicator only addresses SDGs with an environmental component and mostly in a partial manner. In this line, SDGs 1 (on poverty), 4 (on education), 5 (on gender equality), 10 (on global inequalities), 16 (on peace) and 17 (on cooperation) resulted outside of the scope of the Consumption Footprint and were not directly addressed. However, the object of these SDGs are contextual aspects that determine the consumption patterns and intensity, thereby defining the consumption flows assessed by the Consumption Footprint. Overall, the Consumption Footprint can address11 out of the 17 SDGs although mainly partially. Compared with the original mapping by the authors, SDGs 2 and 6 were added as they include sustainable practices in agriculture and energy production, respectively.

In fact, SDG12 was the only goal fully addressed by the Consumption Footprint indicator, as the indicator itself aims at assessing the environmental impacts of consumption and therefore to track advancements towards more sustainable consumption and production patterns. However, the single weighted score of the Consumption Footprint can also be employed to track certain advancements on SDGs 8 (on sustainable economic growth), 9 (on sustainable industrialization) and 11 (on sustainable cities and communities). However, the scope of the Consumption Footprint does not correspond the scope of these goals, as detailed in Table 1.

Finally, the midpoint indicators of the EF2017 method that compose the Consumption Footprint indicator were linked to specific SDGs that address human health and ecosystem quality issues. Diverse midpoint indicators addressed partial aspects of SDGs 2 (on sustainable agriculture), 3 (on human health), 6 (on sustainable water management), 7 (on sustainable energy), 13 (on climate action), 14 (on marine environment) and 15 (on terrestrial ecosystems). The midpoint indicator mainly quantified the impact of the aspect addressed by the SDG goal (e.g., climate change). However, the coverage of SDG3 by midpoint indicators was indirect as only endpoint methods can address the effects on human health (e.g., morbidity, mortality).

Table 1. *Mapping at the goal level: Relation between SDGs and the Consumption Footprint indicator (SDGs can be fully – dark green – or partially – light green – addressed).*

Sustainable Development Goal	Consumption Footprint (CF) indicator
1. End poverty in all its forms everywhere	Not directly addressed.
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture	Partially addressed: The CF indicator can track the environmental profile of consumed agricultural and food products. LU and WU midpoint indicators can be linked to the scope of this goal.
3. Ensure healthy lives and promote well-being for all at all ages	Partially addressed: Seven midpoint indicators of the CF indicator set address effects on human health: CC, ODP, HTOX_c, HTOX_nc, PM, IR and POF.
4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	Not directly addressed
5. Achieve gender equality and empower all women and girls	Not directly addressed
6. Ensure availability and sustainable management of water and sanitation for all	Partially addressed: Four midpoint indicators of the CF set address water quality and consumption: FEU, MEU, ECOTOX, and WU.
7. Ensure access to affordable, reliable, sustainable and modern energy for all	Partially addressed: The CF indicator set includes the midpoint indicator resources use, fossil that is linked to the use of non-renewable sources of energy.
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	Partially addressed: The CF indicator (weighted single score) can be employed to track sustainable economic growth, e.g. decoupling.
9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	Partially addressed: The CF indicator (weighted single score) quantifies the environmental impacts of consumed products, which are influenced by sustainable industrialization.
10. Reduce inequality within and among countries	Not directly addressed.
11. Make cities and human settlements inclusive, safe, resilient and sustainable	Partially addressed: The CF indicator (weighted single score) quantifies the environmental impacts of consumption, being mobility and housing a relevant aspect for urban contexts. The midpoint indicators PM and POF are relevant for assessing air quality in cities.
12. Ensure sustainable consumption and production patterns	Fully addressed: The CF indicator (weighted single score) aims at assessing sustainable consumption and production.
13. Take urgent action to combat climate change and its impacts	Partially addressed: The midpoint indicators of the CF indicator set address climate change: CC, ODP.
14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development	Partially addressed: The midpoint indicators of the CF indicator set address the quality of marine ecosystems: CC, FEU, MEU, and WU.
15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Partially addressed: The midpoint indicators of the CF indicator set address the quality of terrestrial ecosystems: ODP, AC, TEU, LU, ECOTOX, WU, and MRD.
16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	Not directly addressed.
17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development	Not directly addressed.

Midpoint indicators abbreviations are detailed in Figure 1

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3.2. Addressing SDGs at the target level

The link between the Consumption Footprint indicator and the SDGs can be assessed not only at the general goal level, but also more specifically at the target level (Table 2). This lower level of assessment unveiled a different link between SDGs and the Consumer Footprint indicator compared to the goal level (Table 1), allowing to determine whether the link was full or partial. In general, the analysis revealed that the Consumption Footprint indicator can be used to assess a number of targets across different SDGs; but it cannot fully address any SDG when considering the specific targets as they also include qualitative indicators, such as the implementation of policies, the cooperation among countries or budget distribution.

The Consumption Footprint weighted score can be used to monitor SDG12, target 8.4 on global resource efficiency and decoupling and target 11.6 on the environmental impact of cities. It can partially address targets 9.1 and 9.2 as an improved trend of the Consumption Footprint would indicate more sustainable industrialization and infrastructure. Target 2.4 on sustainable agriculture cannot be directly addressed by the indicators as specific aspects of agricultural production are not quantified individually. However, being food the main element of the environmental profile of consumption (Sala et al., 2019a), the Consumption footprint weighted score can be used as proxy to indicate the trend of sustainable agriculture practices that affect the overall environmental impact of food production within consumption.

Moreover, regarding the midpoint indicators, the 16 indicators can also be related to specific SDGS targets. PM and IR were the only two indicators with one indirect relation with SDG targets, whereas all other midpoint indicators showed a direct relation with one to three SDG targets (Table 2).The indicators showing the largest number of relations to SDGs targets (five in total) were the Consumption Footprint weighted score and CC, including indirect relations.

The detailed relations between indicators and targets are here detailed:

- Concerning SDG6, five indicators were related to target 6.3 on water quality, mainly regarding toxicity and eutrophication aspects. WU can monitor target 6.4 on water-use efficiency and LU can partially address target 6.6 on protecting and restoring water-related ecosystems.
- The indicator of FRD can partially address two targets of SDG7 (7.2, 7.3), which tackle increased use of renewable energy and enhanced energy efficiency. In this sense, a decreasing trend of this indicator would indicate an improved situation of these energy-related targets.
- Eight different midpoint indicators showed a relation with three targets of SDG12: 12.2 on efficient use of natural resources, 12.4 on management of chemicals and 12.5 on waste generation.
- Since SDG13's targets can address climate action instead of impacts related to climate change, the midpoint indicator CC showed partial relation to target 13.2. A better implementation of climate policies would show a decreasing trend of this indicator.
- Targets 14.1 and 14.2 on marine pollution and ocean acidification can be partially covered by three

indicators: MEU, FEU and CC.

- Eight midpoint indicators had a direct relation with target 15.1 on sustainable use of terrestrial and ecosystem services, while LU can also address target 15.5 on degradation of natural habitats.

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Table 2. Mapping at the target level: Relation between SDGs and Consumption Footprint indicators (yellow – indirect relation, green – direct relation). Numbers indicate the amount of targets addressed by an indicator for the specific SDG.

SDG	CC	OD	HTOX, c	HTOX,nc	PM	IR	POF	AC	TEU	FEU	MEU	LU	ECOTOX	WU	FRU	MRU	CF, single
1																	
2																	1
3	2	2	2	2	2	2	2			1	1		1				
4																	
5																	
6			1	1						1	1	1	1	1			
7															2		
8															1	1	1
9																	2
10																	
11																	1
12			1	1			1					1	1	1	1	2	1
13	1																
14	1									1	1						
15	1	1						1	1	1		2	1			1	
16																	
17																	
TOTAL	**5**	**3**	**4**	**4**	**2**	**2**	**3**	**1**	**1**	**4**	**3**	**4**	**4**	**2**	**4**	**4**	**5**

See SDG descriptors in Table 1. Midpoint indicators abbreviations are detailed in Figure 1

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Regarding SDG3, the relation between indicators and targets was an indirect relation. SDG3's targets showed relation with 10 midpoint indicators of the Consumption Footprint. However, targets tackle effects on human health (e.g. number of deaths or incidence) while the environmental impact indicators, at the midpoint level as in the EF2017 method, do not. Thus, the indicated relation between SDG targets and indicators relied on an indication of environmental impacts that can affect the target. Therefore, the trend of the environmental impact could give an indication on expected trends of the indicator. For example, a higher climate change impact could negatively affect target 3.3 on tropical diseases.

When exploring the different relations between SDG targets and the Consumption Footprint indicator, the network analysis revealed four main groups within the network (Figure 3). First, the largest group of interactions was composed by ecosystems quality-related impacts and SDGs 6, 13, 14 and 15. Second, several impact categories were linked to SDGs 3 and 6 in relation to human health-impacts. Third, a group of SDGs was mainly linked to indicators of resources use (mineral and fossil) and the Consumption Footprint weighted score. SDG12 showed interactions with these three groups, being located in a central position of the network. Finally, some SDGs were disconnected from the network as they address contextual issues, as previously discussed. As well, the assessment indicated that the Consumption Footprint weighted score had the largest amount of single relations to SDGs (9, 11, 12) (i.e., where no other indicator was linked to SDG targets). SDGs 7 and 13 had also exclusive links to FRD and CC, respectively.

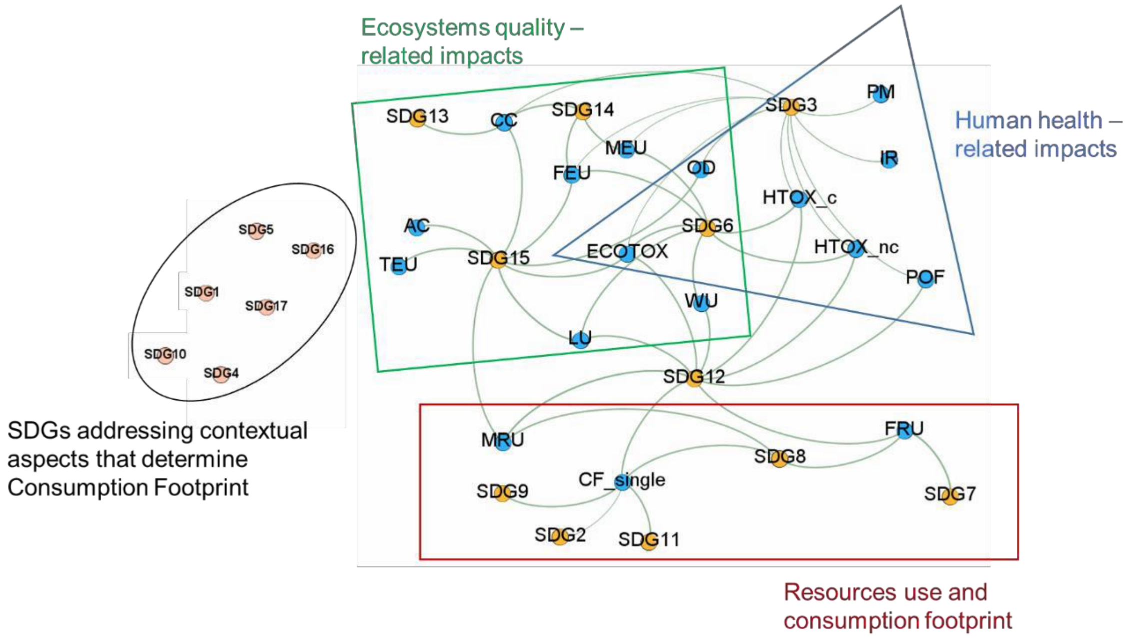

Figure 3. Network analysis and groups of target-indicator relations. *Midpoint indicators abbreviations are detailed in Figure 1*

3.3. Addressing SDGs at the indicator level

The lowest level of the assessment investigated the relations between the Consumption Footprint and the SDG indicators, including a mapping with the Eurostat SDG indicators and the PBs. Table 3 and 4 report those

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targets with indicators that could be related with any of these three indicator sets. In general, the analysis unveiled that

the SDG scheme interprets in a particular way the scope of each target thereby using specific indicators. In this sense, the Consumption Footprint indicators fell sometimes far from the type of indicator selected in the SDGs framework, but could be seen as potentially relevant complementary indicators to assess the actual achievement of SDGs.

3.3.1. Monitoring SDG12 on sustainable consumption and production

Regarding SDG12, three out of the 13 proposed indicators could be covered by Consumption Footprint midpoint indicators (covering three out of 11 targets), in line with the coverage of Eurostat indicators (Table 3). Nonetheless, these indicators can only partially address the coverage of the SDG indicator or be used as proxy for the purpose of the indicator. Their scope was different from that of the SDG indicator, meaning that they cover some of the aspects tackled by the SDG indicators as well as other complementary aspects:

- First, the indicators 12.2.1 (Material footprint) and 12.2.2 (Domestic Material Consumption) were mapped with the midpoint indicators on resource use (fossils and minerals and metals). However, these two indicators do not include biomass, contrarily to the material footprint (UNEP, 2016). In fact, these indicators are used as underpinning data of the Consumption Footprint inventory.
- Second, the proposed indicator to monitor the management of chemicals (12.4.1) addresses policy aspects
  rather than the amount of chemicals employed. The midpoint impacts related to toxicity (both human and ecological) could be employed as proxy to monitor the impact of the use of chemicals, making a step ahead compared to the proposed Eurostat indicator which stops at the pressure level (Consumption of toxic chemicals).
- Finally, the Consumption Footprint weighted score and the midpoint indicator climate change could be
  employed as indicators at the goal level, as some indicators used by Eurostat that showed no link with any specific SDG target.

Regarding the other SDG12 indicators, three quantitative indicators reporting environmental pressures were not covered by Consumption Footprint indicators: Global food loss index (12.3.1), Hazardous waste generation per capita (12.4.2) and National recycling rate (12.5.1). However, these environmental pressures are part of the inventory of the Consumption Footprint. The remaining SDG12 targets (not shown in Table 2) addressed policy issues considering aspects such as the relevance of specific policies on the topic (e.g., subsidies to fossil fuels), the implementation of a topic through policy (e.g., number of countries applying a certain strategy, number of sustainable policies) or cooperation with developing countries.

When mapping SDG indicators and PBs, only target 12.4 on management of chemicals could be monitored with “novel entities”, although the latter has not been quantified yet (Steffen et al., 2015). As well, the PB climate change could be used at the SDG12 goal level.

Table 3. Mapping at the indicator level: Relation between SDG12 indicators, Consumption Footprint indicators, Eurostat indicators and the PBs (yellow – proxy indicators, orange – partial coverage).

Target	Indicator	Consumption Footprint indicator	Eurostat indicator	PBs
SDG12		Consumption Footprint weighted score CC	Average CO_2 emissions per km from new passenger cars Primary energy consumption	Climate change
12.2 By 2030, achieve the sustainable management and efficient use of natural resources	12.2.1 Material footprint, material footprint per capita, and material footprint per GDP	FRD MRD	Resource productivity (GDP/DMC)	
		Consumption Footprint (inventory)		
	12.2.2 Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP	FRD MRD Resource use, minerals and metals	Domestic Material Consumption	
		Consumption Footprint (inventory)		
12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment	12.4.1 Number of parties to international multilateral environmental agreements on hazardous waste, and other chemicals that meet their commitments and obligations in transmitting information as required by each relevant agreement	HTOX_c HTOX_nc ECOTOX	Consumption of toxic chemicals	Novel entities
	12.4.2 Hazardous waste generated per capita and proportion of hazardous waste treated, by type of treatment	Consumption Footprint (inventory)		Novel entities
12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse	12.5.1 National recycling rate, tons of material recycled	Consumption Footprint (inventory)	Circular Material Use (CMU) ratio Recycling rate of waste excluding major mineral wastes Generation of waste (excl. major mineral waste)	

Midpoint indicators abbreviations are detailed in Figure 1

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3.3.2. Monitoring other SDGs at the indicator level

The Consumption Footprint indicator showed relation with SDGs 2, 3, 6, 7, 8, 9, 11, 13, 14 and 15. Table 4 details the mapping at the indicator level for these SDGs. Although the Consumption Footprint indicator was not designed to address other SDGs at the goal level, its results can monitor targets of multiple SDGs. In most of the cases, the Consumption Footprint indicators can address only partially or as a proxy, as already observed for SDG12. Here again, the Consumption-Footprint indicators can be seen as relevant complements to the existing framework of SDG indicators, going beyond the latter with respect to several important aspects.

Table 4. Mapping at the indicator level: Relation between SDG indicators, Consumption Footprint indicators, Eurostat indicators and the PBs (orange – partial coverage, yellow– proxy indicators).

SDG	Target	Indicator	Consumption Footprint indicator	Eurostat indicator	PBs
3	3.4 By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being	3.4.1 Mortality rate attributed to cardiovascular disease, cancer, diabetes or chronic respiratory disease	HTOX_c HTOX_nc PM POF	Death rate due to chronic diseases	Novel entities Atmospheric aerosol loading
	3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination	3.9.1 Mortality rate attributed to household and ambient air pollution		(Among other indicators) Exposure to air pollution	Atmospheric aerosol loading
6	6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	6.3.2 Proportion of bodies of water with good ambient water quality	FEU ECOTOX	Nitrate in groundwater BOD in rivers Phosphate in rivers	Biogeochemical cycles
	6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	6.4.1 Change in water-use efficiency over time	Consumption Footprint (inventory)		Freshwater use
		6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	WU	Water exploitation index	Freshwater use
7	7.3 By 2030, double the global rate of improvement in energy efficiency	7.3.1 Energy intensity measured in terms of primary energy and GDP	FRD	Final energy consumption	
8	8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-Year Framework of Programmes on Sustainable Consumption and Production, with developed countries taking the lead	8.4.1 Material footprint, material footprint per capita, and material footprint per GDP	FRD MRD	Resource productivity (GDP/DMC)	
		8.4.2 Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP	FRD MRD	DMC	

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9	9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities	9.4.1 CO_2 emission per unit of value added	CC	Average CO_2 emissions per km from new passenger cars	Climate change
11	11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries	11.3.1 Ratio of land consumption rate to population growth rate	LU	Artificial land cover	Land-system change
		11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)	PM	Exposure to air pollution	Atmospheric aerosol loading
SDG 13			CC	Greenhouse gas emissions Greenhouse gas emissions intensity of energy consumption	Climate change
14	14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution	14.1.1 Index of coastal eutrophication and floating plastic debris density	MEU	Coastal bathing sites with excellent water quality	
	14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels	14.3.1 Average marine acidity (pH) measured at agreed suite of representative sampling stations	CC	Mean ocean acidity	Ocean acidification
15	SDG 15			BOD in rivers Nitrate in groundwater Phosphate in rivers	
	15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements	15.1.1 Forest area as a proportion of total land area	LU	Share of forest area	Land-system change
		15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type		Surface of terrestrial sites designated under Natura 2000	Biosphere integrity

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				Common bird index Grassland butterfly index	
	15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world	15.3.1 Proportion of land that is degraded over total land area	LU	Estimated soil erosion by water Soil sealing index	Land-system change

Midpoint indicators abbreviations are detailed in Figure 1

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3.3.4. Limitations of the Consumption Footprint in the coverage of SDG indicators

The Consumption Footprint indicator was designed for monitoring SDG12 at the goal level, thereby indicating the progress of sustainable consumption and production. However, the assessment at the target and indicator levels unveiled some limitations of the Consumption Footprint indicator for fully addressing SDG12. First, although the Consumption Footprint can give an idea of the progress towards SDG12, not all the targets were covered by the quantitative environmental indicators composing the Consumption Footprint set. This was caused by the fact that some SDG indicators address qualitative aspects, such as policy implementation.

Second, LCA indicators sometimes do not quantify the same specific aspect of a SDG target or indicator thereby providing a partial coverage or limiting the role of the indicator as a proxy. For example, LCA indicators on resource use exclude some resources that were considered in the approach taken by the SDGs, i.e. the material footprint. While the two resource use indicators included in the Consumption Footprint differentiate between fossils and mineral and metals, they do not consider the whole set of resources included in material flows (e.g., biomass). However, it is noteworthy that LCA indicators are particularly relevant in the context of mineral resources, for which some metals extracted in relatively minor quantities may present very minor contributions to mass-based indicators, but at the same time large contributions to impact-based indicators (e.g., regarding the impacts of EU trade on mineral and metal resource use; Beylot et al., 2019).

Although the SDGs scheme indicates the use of the Domestic Material Consumption (DMC) and the material footprint as resource efficiency indicators, discussions in the literature also proposed other indicators with different system boundaries: the Raw Material Consumption (RMC) and the Raw Material Input (RMI) (Guyonnet and Pasquier, 2019). The trends for the period 2004-2011 of these indicators were compared to the Consumption Footprint indicators related to resources (Figure 4):

- The characterized indicators: resources use, fossil (FRU); resources use, minerals and metals (MRU); land use (LU); and water use (WU)
- The normalized and weighted aggregated indicators: RD, norm (including FRD; MRD; LU and WU) and RD, abiotic, norm (including FRD and MRD)
- The Consumption Footprint top-down weighted score (CF-TD)

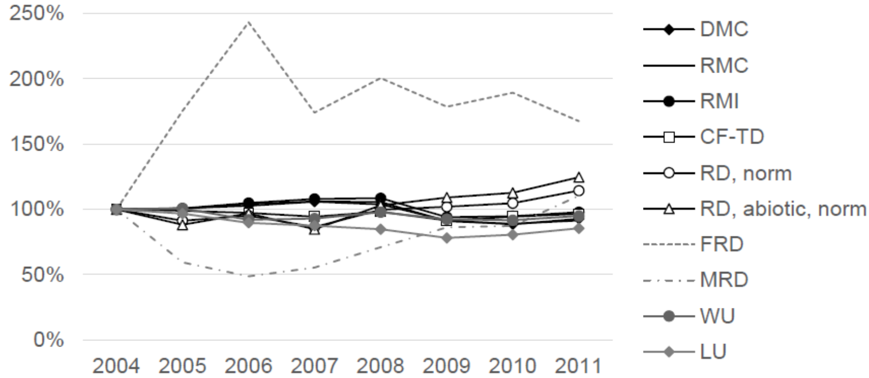

Figure 4. Comparison of the trends of the resource indicators DMC, RMC and RMI with the Consumption Footprint indicators: CF-TD, FRD, MRD, RD, norm and RD, abiotic, norm.

For the EU-28, the DMC and RMC showed very similar trends, which were close to the RMI trend. Among the Consumption Footprint indicators, the CF-TD showed a similar trend to these indicators. Contrarily to the resources indicators, showing disconnected trends. Although being in the same range, the aggregated indicators (normalized and weighted) had an increasing trend, contrary to the resource efficiency indicators.

Furthermore, data availability can represent a barrier for quantifying the trade component of the Consumption Footprint indicator. On the one hand, the bottom-up approach has been only developed for the EU-28 geographic area and no Member State results are available yet. On the other hand, the top-down approach employs data from the Exiobase 3 database (hybrid version; Merciai and Schmidt, 2017; Stadler et al., 2018; Wood et al., 2015), which has available data only until 2011 and calculations beyond this year require extrapolation that would increase the uncertainty of the results.

Towards covering the overall SDGs, the scope of the Consumption Footprint indicator was limited to address the environmental dimension of sustainability. In this sense, several goals that focus on social aspects (e.g., SDG1 on poverty) are beyond the scope of the Consumption Footprint. However, recent advancements in LCA have targeted the social impacts of products resulting in the development of social LCA (S-LCA) (UNEP, 2009). Therefore, potential developments of the Consumer Footprint indicator towards integrating S-LCA indicators could enlarge the coverage of SDG goals and specific targets. As well, some aspects of ecosystem quality (e.g., marine litter, biodiversity) are under development in the LCA community and could in the short-term broaden the coverage of SDG targets.

3.4. Relevance of the Consumption Footprint for the assessment of SDGs

Employing LCA-based indicators for monitoring SDGs, as a complement to SDG indicators, would provide several benefits with a view to truly assess the actual achievement of the SDGs. First, the proposed Consumption Footprint (EF2017 method) quantifies potential environmental impacts beyond the mere pressure-based

footprints. In this sense, the different impact potential of similar pressures (e.g., emissions to the environment of two different chemicals) would be recognized. Second, the Consumption Footprint indicator provides a consumption-based approach that includes both domestic and trade impact. In fact, trade can determine the environmental impacts resulting from the consumption patterns of a territory, as for the EU which is a net importer of environmental burdens (Sala et al., 2019a). Therefore, employing consumption-based indicators rather than domestic (i.e., territory-based) indicators is essential towards ensuring a global sustainable development, as discussed in the literature (Wood et al., 2018).

Furthermore, some environmental aspects addressed in the Consumption Footprint by the different midpoint categories were not linked to specific targets neither indicators. Thus, the missing indicators could be used as complementary indicators for monitoring SDGs (e.g., SDG12 at the goal level). In fact, the implementation of the SDG scheme showed some limitations in their application to case studies, where alternative or new

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indicators were necessary to monitor the different targets, e.g. Australia (Allen et al., 2019).

Finally, the analysis revealed that some links between the Consumption Footprint and the SDGs framework is partial or missing. However, some aspects included in the SDGs are considered in the life cycle inventory phase as contextual aspects or environmental pressures, which are then characterized as environmental impacts in the impact assessment phase (Figure 5).

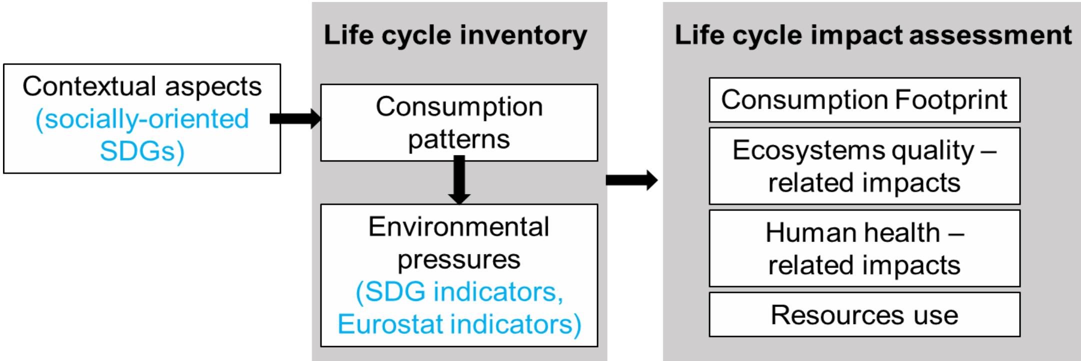

Figure 5. Relation of the life cycle inventory and impact assessment phases with the coverage of SDGs by the Consumption Footprint.

4. Conclusions

The Consumption Footprint was designed as an LCA-based indicator to quantify the environmental impacts of consumption in the EU and to monitor the progress towards SDG12 on sustainable consumption and production. Although results showed that the economic growth of the EU decoupled from the environmental impacts of consumption between 2005-2014, the environmental burdens of consumption were not sustainable from an absolute perspective as PBs were surpassed for some categories. According to these results, EU would have made progress towards achieving SDG12. However, the detailed coverage of SDG12 by the Consumption Footprint was not evaluated. In this context, this paper aimed to investigate the actual coverage of SDGs by the Consumption Footprint indicator from the goal to the indicator level.

Although designed to monitor SDG12, the assessment unveiled that the Consumption Footprint can also address aspects of SDGs 2, 3, 6, 7, 8, 9, 11, 13, 14 and 15. At the goal level, the coverage of these goals was partial, apart from SDG12. At the target level, results showed that the Consumption Footprint indicator can be used to assess a number of targets across different SDGs; but it cannot fully address any SDG, even SDG12 on sustainable consumption and production. The same pattern was observed at the indicator level. This fact was related to the high specificity of SDG targets, which also include qualitative indicators addressing aspects such as budget distribution, the implementation of policies or cooperation among countries. This characteristic of the SDGs resulted from the high political component (Miola and Schiltz, 2019).

The Consumption Footprint indicators appear as potentially relevant complementary indicators to assess the actual achievement of SDGs. The Consumption Footprint monitors impacts rather than pressures and the different effects of resources from or emissions to the environment are, thus, embedded in the Consumption Footprint. Second, there is a need to evaluate the environmental impact of territories from a consumption-based approach rather than a territorial one. Finally, some midpoint indicators that are not included in the SDGs framework could complement the current SDG selection.

Since Eurostat developed a set of indicators to monitor the progress towards SDGs in the EU, the coverage of the Consumption Footprint at the indicator level was compared with the Eurostat set for the relevant targets. As well, the coverage was contrasted with the potential monitoring with the PBs as absolute thresholds. The coverage of the SDGs indicators by the Consumption Footprint was similar to the Eurostat SDGs indicator set and the PBs scheme, which also showed partial coverage of indicators and alternative indicators used as proxy. New developments in LCA could be implemented in the Consumption Footprint to broaden the scope of this LCA- based indicator and enlarging the coverage SDGs, such as social LCA and socially-oriented SDGs or further developments in quantifying ecosystem quality (e.g., marine litter, biodiversity).

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The Satisfaction and Usage of Public Transport Trends and Determinants in European Union

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Abstract
Transport sector contributes to vast of problems: traffic, energy consumption, noise, pollution and related health and environmental impacts. Thus, the promotion of public transport usage is one of the main tools to reduce these problems and strive for sustainability. As public transport usage depends on many of factors, the aim of this study was to evaluate current level of public transport satisfaction, usage and its determinants in European Union (EU). Referring to the Eurobarometer's survey (2014) the results showed that the level of public transport usage in EU is rather low and it significantly depends on countries' economic development. In economically stronger countries respondents tend to use public transport less. The satisfaction levels of public transport as: frequency and reliability, comfort and safety, price of tickets and amenities at stop and station differed among EU countries as well. Applied regression analysis showed that in a half of EU countries the satisfaction of ticket price and the distance to nearest stations had significant impact on public transport usage. Meanwhile in one third of EU countries the satisfaction with public transport frequency and reliability and satisfaction with comfort and safety had significant effect on public transport usage. Furthermore, in majority EU countries women and older respondents tend to use public transport more often. Therefore, this study is very important for enhancement of public transport service and usage in separate EU countries considering their different situations and possible measures.

Keywords: Satisfaction; Public transport; Sustainability; European Union; Distance To Station or Stop.

1. Introduction

Transport sector in recent decades grow very fast and contributes to air pollution, energy consumption, GHG emissions (Cruz and Katz-Gerro, 2016; Zailani et al., 2016; Siskos et al., 2018; Letnik et al., 2018), traffic congestion, road accidents, increase noise (Woods and Mashthoff, 2017), and related health impacts (WHO, 2011). Hence, the promotion of public transport (PT) usage is one the tool to reduce these problems (Dirgahayani, 2013; Replogle and Fulton, 2014; Aggarwal and Jain, 2016; Liu et al., 2017; Abenoza et al., 2017; Chen et al., 2018) and has the potential benefit of enhancing social inclusion (Lucas, 2006; Margarita et al., 2017; Cascajo et al., 2018) and contributes seeking sustainability (Hiselius and Rosqvist, 2016; Chen et al., 2018; Mugion et al., 2018; Nguyen-Phuoc et al., 2018). Thus, PT service is the most important component of a sustainable transportation system in the world and even in European Union (EU) countries (Abenoza et al., 2017).

However, referring to Eurostat (2012) and European Platform on Mobility Management (2014) reports the share of PT was in 2011 and 2012 in EU countries only 16–17% of the total passenger travel. Therefore, the overall objective of the European transport policy to increase the share of PT and to reduce the use of private cars (Bryniarska and Zakowska, 2017) remains a challenge.

Usage of PT very much depends on the service quality and accessibility and affordability. Hence, the improvement of service quality is one of the main aspects of PT usage (Beirão and Cabral, 2007; Şimşekoğlu et al 2015; Zailani et al., 2016; Cruz and Katz- Gerro, 2016; Mugion et al., 2018). Service quality lies in the product quality and the customer satisfaction (Brady and Cronin, 2001; Mugion et al., 2018). Authors (Friman and Gärling, 2001; Gärling et al., 2018) analysing the quality of PT service suggest to include and evaluate the satisfaction level as user satisfaction is a key indicator of PT service quality (Chica-Olmo et al., 2018) and reveals the image of the operator, travellers' expectations, and the perceived quality of service (Fornell, 1992; Morfoulaki et al., 2010; Abenoza et al., 2017). The PT service quality (Eboli and Mazzulla, 2007; Fellesson and Friman, 2008; Tyrinopoulos and Aifadopoulou, 2008; Le-Klähn et al., 2014; Imam, 2014; Mugion et al., 2018) and separate components of service quality impact on general satisfaction of PT services or the characteristics of commuters (Ettema et al., 2012; Fiorior et al., 2013; St-Louis et al., 2014; De Oña and de Oña, 2015; Abenoza et al., 2017; Lois et al., 2018; Chica- Olmo et al., 2018; Friman et al., 2019 and etc.) are extensively analysed. Meanwhile the satisfaction of PT service impact on usage of PT is analysed rather scarcely (Mouwen 2015; Irtema et al., 2018; Mugion et al., 2018). Considering the studies on EU countries, Woods and Masthoff, (2017) compared the car driving, public transport and cycling experience in Finland, Spain and Italy. Chica-Olmo et al. (2018) and Lois et al. (2018) analysed the satisfaction of public service quality factors in Spain, Mouwen (2015) in the Netherlands, Abenoza et al. (2017) and Jenelius, (2018) in Sweden and Fiorio et al. (2013) in 33 European cities. Not much is done on the satisfaction impact on PT usage in EU. Only Efthymiou and Antoniou (2017) explored how satisfaction of PT service contributes to usage of PT in Spain and Mouwen (2015) revealed how overall satisfaction influence PT usage in the Netherlands. However, the main question remains for transport operators and authorities, which PT service quality attributes are the most important for people and could contribute to the enhancement of PT usage in EU countries (Ngoc et al., 2017).

Usually analysed PT service quality and satisfaction categories vary. Efthymiou and Antoniou (2017) separated satisfaction factors to quality of service (related to behaviour, vehicle conditions, price), transfer quality (related to waiting time, provision of information, distance) and service production (related to service frequency and reliability). Chica-Olmo et al., (2018) summarized quality components into two categories: the technical

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dimension and the functional dimension or "comfort" and "services supply factors". Ngoc et al., 2017 classified satisfactions into four categories: comfort and security, service quality, planning quality and reliability. Fellesson and Friman (2008) comparing the users' satisfaction of public transport identified that satisfaction is affected by four factors: comfort, staff, system and safety. Lois et al (2018) classified factors to: information, transfer conditions, safety and security, emergency situation, design and image and services and comfort. Şimşekoğlu et al (2015) separate quality attributes into flexibility; convenience and safety and security. Chowdhury and Ceder (2016) in the literature review summarised factors to: safety and security, reliability, transfer time (walking and waiting), information systems for users, ticketing and fare systems, comfort and amenities at interchanges/ stations. Thus, the literature review reveals that there is no one classification of PT satisfaction categories. In this paper we classified the satisfaction to four categories (frequency and reliability, comfort and safety, price of tickets and amenities at stop and station). Furthermore, considering that expectations of users (or satisfaction of PT service) vary significantly among different countries (Ngoc et al., 2017), it is important to analyse how different categories of service satisfaction influence PT usage in separate EU countries.
Additionally, in line with good level of service quality, an extensive coverage is the most important component of PT system (Chowdhury and Ceder, 2016; Abenoza et al., 2017; Woods and Mashthoff, 2017; Bryniarska and Zakowska, 2017; AlRukaibi and AlKheder, 2019). Authors (Brons et al., 2009) found that low accessibility measures negatively affect the overall assessment of the travel experience and the PT usage. Therefore, it is important to continue to invest not only in a reliable, comfortable, safe, and flexible, but also in accessible PT (Mees, 2010; Friman et al., 2019). Access to PT is evaluated as perceived walking time to and from stops and stations (Kingham et al., 2001, Galdames et al., 2011; Chowdhury and Ceder, 2016). The distance to stations is particularly important for old people (Truong and Somenahalli, 2015) and PT interchanges (Bryniarska and Zakowska, 2017). Meanwhile Şimşekoğlu et al (2015) found that time from home to nearest PT stations insignificantly influenced the usage of PT in Norway.

Socio-demographic variables is also important aspects in term of PT usage (Chowdhury and Ceder, 2016; Yang et al., 2018; Friman et al., 2019). According to Eurobarometer repots (2011) major user groups of public transport are women and young people (particularly students). Buehler and Pucher (2012) have noted a slight increase in use among young men. Meanwhile Woods and Mashthoff (2017) found no significant age and gender differences for liking of public transport in three EU countries. Şimşekoğlu et al (2015) revealed that only age and not gender influence the usage of PT in Norwegian.

Despite a high attention to the transport system and possible determinants of usage of PT, studies mainly address only separate European countries as Norway (Şimşekoğlu et al 2015), Italy (Mugion et al., 2018), Spain (Efthymiou and Antoniou, 2017, Cascajo et al., 2018), Estonia (Hess, 2017), or small groups of EU countries (Belgium, Germany, Greece, Italy, the Netherlands) (Margarita et al., 2017). To the best of our knowledge none of researches did analyse the tendencies and determinants of PT usage in all EU countries together, thus this study contributes to filling this gap. Furthermore, as this study encompass all EU countries, it is relevant to consider how countries economic development influence the PT usage. In the literature, only Invardson and Nielsen (2018) analysed how PT ridership depends on GDP in 48 European metropolitan areas and found that in richer countries is higher level of PT ridership. Thus, the aim of this study was to evaluate current level of public transport satisfaction, usage and its determinants in European Union (EU), which are varied in cultural, geographical, level of service and infrastructure provided.

2. Methods

The satisfaction and PT usage in the EU were analysed referring to the survey "Europeans' satisfaction of with urban transport", which was conducted by Eurobarometer in 2014. The respondents in all EU countries from different social and demographic groups were interviewed via telephone. The detailed interview methods and confidence intervals are presented in a report by the European Commission (EC, 2014). The study covers all EU countries: AT-Austria, BE-Belgium, BG-Bulgaria, CY-Cyprus, CZ-Czech Republic, DK-Denmark, EE-Estonia, ES-Spain, FL-Finland, FR-France, GE-Germany, GR-Greece, HR-Croatia, HU-Hungary, IE-Ireland, IT-Italy, LV-Latvia, LT-Lithuania, MT-Malta, NL-Netherlands, PL-Poland, PT-Portugal, RO-Romania, SK-Slovakia, SL- Slovenia, SE-Sweden, and UK-United Kingdom. In this study, only Luxemburg was excluded. The PT usage were estimated by the answers of question: "How often do you travel by urban public transport Bus, metro, tram, etc." The answers were from 1 – Daily/ almost daily to 7-never. In order to evaluate the impact of economic development on PT usage (mean level of PT usage in separate country) the gross domestic product (GDP) per

capita in purchasing power parity (constant 2011 international $) in 2014 was used. To evaluate this relationship, the Spearman correlation coefficient was applied. satisfaction of PT service was separated to four categories: frequency and reliability, comfort and safety, price of tickets and amenities at stop and station. The items of satisfaction scales are presented in Table 1. All constructs were measured using five-point Likert scale ranging from very satisfied (1) to not applicable (5). The reliability statistics by applying Cronbach's alpha were presented in Table 2. As we see the Cronbach's alpha vary from 0,55 to 0,87. Considering that denoting strong reliability among measures Cronbach's alpha for constructs must exceed the cut-off point of 0.7 (Nunnally and Berstein, 1994; Hair et al., 2010), thus, from the analysis Germany, Portugal, Finland, Latvia, Cyprus and Malta were excluded, because the values were less than 0,7. For latter two countries there was a lack of price of tickets satisfaction data.

Table 1. *Items of PT service satisfactions scales.*

Construct	Items
Frequency and reliability	• I am satisfied with frequency of service • I am satisfied with punctuality and reliability
Comfort and safety	• I am satisfied with the routes taken by the different urban lines • I amI am satisfied with passenger security • I am satisfied with cleanliness and good maintenance of vehicles/carriages

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Price of tickets	• I am satisfied with ease of buying tick • I am satisfied with price of the tickets • I am satisfied with availability of tickets for a journey using several modes (i.e. tram, metro, bus, local trains) • I am satisfied with possibilities to take routes by the different urban lines
Amenities at stop and station	• I am satisfied with provision of information about timetables • I am satisfied with amenities for passengers at stops and stations (e.g. shelter, seats, etc.) • I am satisfied with cleanliness and good maintenance of stops and stations

Table 2. *The Cronbach's alpha of scales*

	Frequency and reliability	Comfort and safety	Amenities at stop and station	Price of tickets
FR N=1004	0,707	0,772	0,744	0,7
BE N=1000	0,767	0,744	0,7	0,7
NL N=1002	0,811	0,819	0,751	0,758
GE N=1000	0,616	0,649	0,683	0,644
IT N=1001	0,787	0,743	0,781	0,7
DK N=1008	0,755	0,819	0,725	0,701
IE N=1000	0,85	0,807	0,789	0,75
UK N=1007	0,797	0,703	0,702	0,70
GR N=1000	0,782	0,768	0,769	0,741
ES N=1001	0,747	0,735	0,741	0,721
PT N=1002	0,667	0,6	0,575	0,562
FL N=1005	0,589	0,661	0,639	0,722
SE N=1000	0,749	0,763	0,757	0,736
AU N=1001	0,764	0,764	0,73	0,73
CY N=501	0,698	0,528	0,567	No data
CZ N=1000	0,73	0,736	0,7	0,743
EE N=1000	0,707	0,786	0,794	0,746
HU N=1003	0,749	0,755	0,707	0,744
LV N=1001	0,549	0,621	0,655	0,559
LT N=1000	0,782	0,722	0,736	0,721
MT N=500	0,834	0,827	0,74	No data
PL N=1001	0,811	0,84	0,834	0,801
SK N=1003	0,847	0,87	0,828	0,83
SL N=1023	0,775	0,833	0,819	0,775
BG N=1000	0,789	0,805	0,743	0,722
RO N=1025	0,798	0,793	0,704	0,746
HG N=1005	0,793	0,813	0,789	0,79

In order to evaluate the determinants of PT usage, generalized linear model was applied. This method was used because in the model is possibility to include the categorized factors as gender and it helps to evaluate the determinants that influence PT usage the most and directly. Referring to the proposed model presented in Fig 1, we analysed the impact of satisfaction levels, distance to get to the nearest station or stop from your home (1- less than 10 minutes to 4 – more than an hour) and social-demographic variables as age and gender on PT usage.

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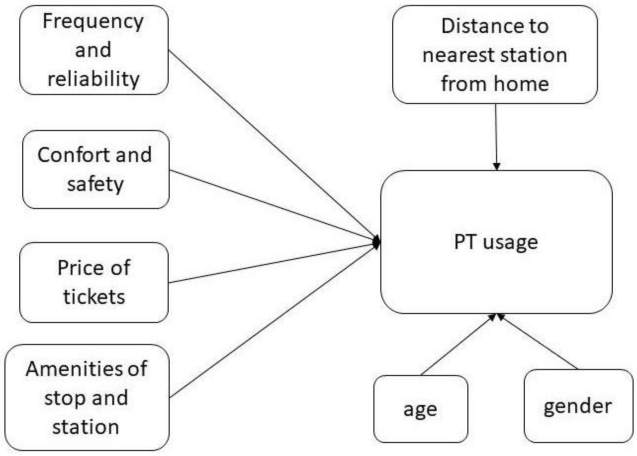
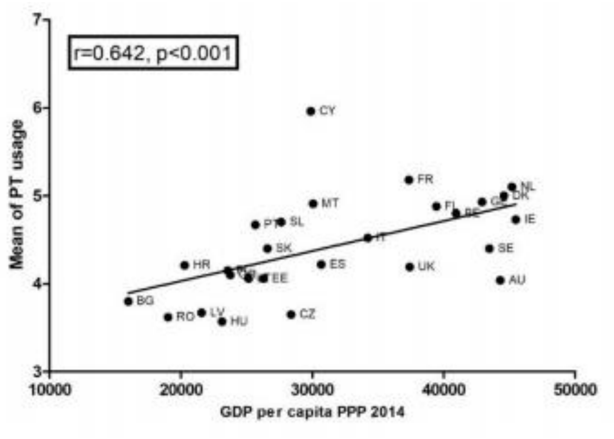


Figure 1. *Proposed model*

3. Results and Discussion

The level of PT usage is rather low in EU countries. In all EU only 15.7 % of respondents stated that they use PT almost daily, and 11.1 % - several times per week. Even 25 % of respondents declared that they never use PT and 10,9 % use it only once a year or less (EC, 2014). This shows that the promotion of PT in EU countries is very serious challenge seeking sustainable transportation system.

Nevertheless, there was observed a big difference in terms PT usage within EU countries. Hungary, Latvia, Czech Republic and Romania are the countries where the level of PT usage is the highest. Meanwhile in Cyprus the level of PT usage was the least. In this country even 62,7 % of respondents never used PT. In France and the Netherland citizens use PT rather seldom as well (Fig. 2). Therefore, particularly in these countries more attention should be paid to trigger and enhance the usage of PT.



4.

Figure 2. *Relationship between mean values of PT usage (1- daily/almost daily, 7- never use PT) and GDP level.*

Furthermore, the results revealed that the level of PT usage significantly depended on economic development of the country (Fig 2). Thus, in richer EU countries citizens tend to use PT more rarely comparing with less rich

EU countries. This result contradicts to Invardson and Nielsen (2018) findings. This contradiction could be explained that Invardson and Nielsen (2018) study encompassed 48 European metropolitan areas in big cities and only in economically developed countries. In our study the poorest EU countries as Romania, Bulgaria, Croatia, where the GDP level is more than two times less than in old EU countries, were included and we analysed the impact of general economic development level of countries on the mean of PT usage. One of the reasons that in poorer EU countries citizens used more PT could be that in these countries not all people can afford to have a car, particularly young or old people. Furthermore, in poorer countries usually family have only one car and PT is a good alternative for those who are without car access. Eurobarometer (2011) and Friman et al (2019) highlighted that major user groups of PT households are without access to cars. Moreover, the cost of PT travel is cheaper and is in the attractiveness of PT services relative to private cars (Fiorio and Percoco, 2007; Nguyen-Phuoc et al., 2018), especially in lower income countries. However, the problem can emerge when less developed EU countries will achieve the income level of old EU countries. Therefore, meeting the growing mobility needs requires integrated actions involving primarily change of travelling behaviour of residents and a significant increase in share of journeys by PT. To reach those targets various PT attributes have to be addressed and considered.

The accessibility and quality of PT service are within the main factors, which can enhance the level of PT usage or promote residents to rethink their traveling behaviour. In terms of distance to nearest station from home, the time to get to the nearest stop differed among EU countries. In Bulgaria, Sweden, Denmark, and the Netherlands most of respondents stated that to nearest station from home takes 10 or less than ten minutes. Meanwhile in Croatia, Slovenia and France the distance to nearest station from home is the longest (Fig 3).

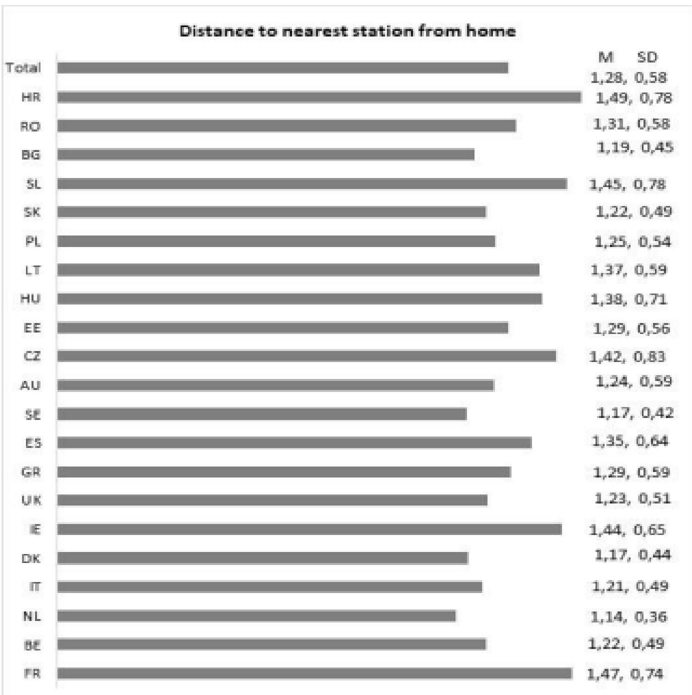


Figure 3. *The time to the nearest PT station from home in EU countries*

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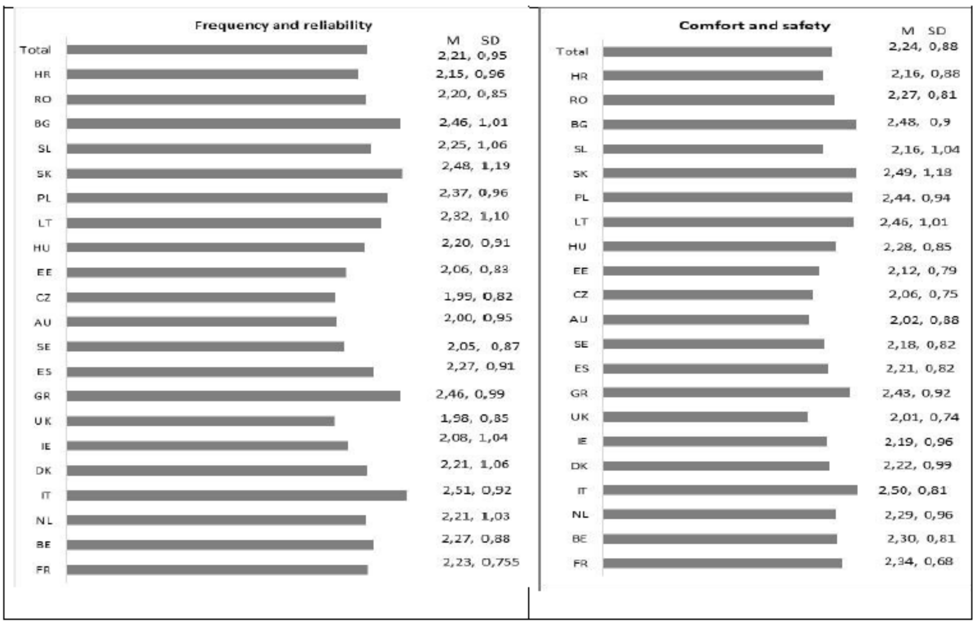
The distance to nearest station is particularly important for people with physical disability. For old people walking time to stops should not exceed five minutes (Truong and Somenahalli, 2015). However, it is recommended that

the standard distance between stations should be between 1-1.4 km (AlRukaibi and AlKheder, 2019). Thus, the reduction of the distance to nearest station from home is rather difficult and requires the compatibility with all parties.

Analysing the satisfaction level of separate PT quality categories, the results showed that the satisfaction level of public transport frequency and reliability, comfort and safety, price of tickets and amenities at stop and station differed among EU countries as well. From Fig 4 we see that in countries as Check Republic, United Kingdom, Austria and Estonia where citizens were rather satisfied with frequency and reliability, they also were satisfied with comfort and safety and amenities of stops and stations. These results reveal that some governmental institutions and PT companies in the EU invest and develop separate quality aspects simultaneously. However, respondents were the least satisfied of these categories in Bulgaria, Italy and Greece. Therefore, in the latter countries particular attention should be paid for the improvement of these PT quality categories.

In term of satisfaction of price of tickets, from all categories of satisfaction respondents were the least satisfied particularly in the Netherlands, Slovakia and Hungary. Only in Austria and Romania citizens stated that they are rather satisfied with price level. However, in order to enhance the level of PT usage, at the beginning not all quality categories are necessary to improve. In next section we will evaluate which of PT service satisfaction categories are the most important for people and could contribute to the enhancement of PT usage in EU countries first and the most.



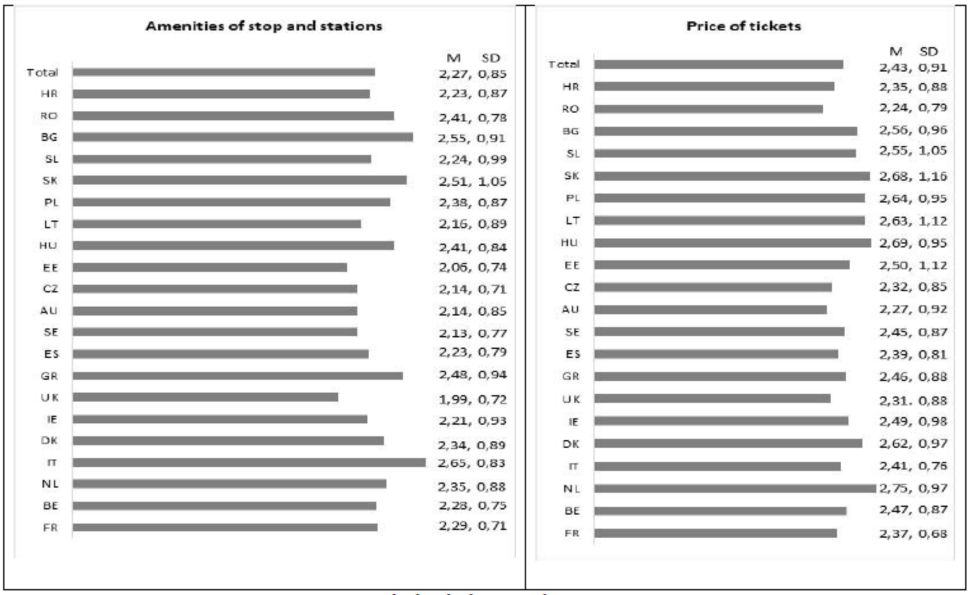


Figure 4. *The level of PT satisfactions in EU countries*

Applying the regression analysis, results revealed that not all satisfaction categories are important to PT usage behaviour. Furthermore, in different EU countries the dissimilar determinants significantly influence the PT usage. Therefore, in order to enhance the ridership of PT, the separate EU country should also consider their peculiarities. As we see from table 3, in half of EU countries (in 11 from 21 countries) age significantly influence the PT usage. Thus, in these countries older people tend to use PT more. Furthermore, in half of EU countries women used more often PT. How to promote the usage of PT for young people and men is a challenge. One of suggestions could be to enhance the image of PT users and introduce some economic or administrative incentives, like limitation of car usage in the cities centre, park and ride schemes, etc.

The distance to nearest station from home significantly effects PT usage in a half of EU countries (in 11 form 21 countries). The shorter distance to station could reduce the travel time by PT and is especially important for people with disabilities (Truong and Somenahalli, 2015). In other hand it is good opportunity to enhance the activity of people. However, to revise the stops and station system is of importance particularly where the distance significantly influence PT usage (as in Check Republic, Poland, Romania and etc.). Public and other stakeholders should be involved in this process.

Considering other satisfaction categories, the satisfaction of price tickets in a half of EU countries (in 11 from 21 EU countries) significantly and positively influenced PT usage. Thus, pricing could be one of key attribute which attracts PT usage (Redman et al., 2013; Chowdhury and Ceder, 2016). Other authors also revealed that the price level particularly is important in Spain (Cascajo et al., 2018), and in UK (Paulley et al., 2006). In Greece increased ticket prices resulted in the reduction of PT usage (Efthymiou and Antoniou, 2017). Dickinson and Wretstrand (2015) stated that in Sweden adoption of free public transport trial periods, especially for commuters, might be an efficient measure to increase PT ridership. However, in other EU countries the satisfaction based on ticket price cannot guarantee the enhancement of PT usage. Hess (2017) analysing the

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fare-free public transport programme in Tallinn (Estonia) found that public transport "free" exhibited lower-than-expected increase in a ridership. As we see from our results for Estonia satisfaction of price of tickets insignificantly influence the usage of PT. Thus, we should not expect that the reduction of price of tickets will contribute to the enhancement of PT usage in all EU countries directly. Other factors might be of importance. For ex. to use a single ticket approach during the all travel by different means of PT could be much easier for passengers (Bryniarska and Zakowska, 2017). Furthermore, in the case of price general finding across studies was that costs of using private vehicles in terms of fuel prices or parking costs were associated with higher public transport ridership (Invardson and Nielsen, 2018). Thus, it is important to consider introducing road pricing and higher parking charges simultaneously (Hess, 2017, Nguyen-Phuoc et al., 2018) with improvement of other PT attributes as PT prices might not be influential as results suggest.

Table. 3. *Regression results of PT usage*

	Amenities at stop and station	Price of tickets	Frequency and reliability	Comfort and safety	Distance to nearest station from home	Age	Gender	R^2
FR	0,005	0,416	0,080	-0,050	0,464	0,233	0,003	0,098
BE	0,149	0,083	0,062	0,419	0,262	0,094	-0,346	0,080
NL	-0,095	0,171	0,260	0,331	-0,123	0,165	-0,198	0,169
IT	0,019	0,432	-0,177	0,185	0,092	0,047	-0,298	0,034
DK	-0,126	0,183	0,296	0,321	0,262	0,116	-0,742	0,191
IE	0,301	-0,107	0,146	0,224	0,475	0,190	-0,238	0,151
UK	0,118	-0,229	-0,045	0,759	0,470	-0,030	-0,028	0,071
GR	0,173	0,698	-0,396	0,202	0,393	0,195	-0,649	0,164
ES	0,042	0,566	-0,221	0,221	0,473	0,175	-0,688	0,113
SE	0,003	0,841	0,024	0,015	0,305	0,171	-0,560	0,184
AU	0,136	0,795	-0,142	0,090	0,379	0,038	-0,083	0,167
CZ	0,045	0,318	0,285	0,185	0,597	0,026	-0,417	0,160
EE	0,406	0,224	0,199	0,193	0,444	-0,002	-0,469	0,187
HU	-0,098	-0,178	0,111	0,695	0,409	0,178	-0,201	0,113
LT	-0,051	0,460	0,122	-0,054	0,086	0,026	-0,133	0,271
PL	0,410	-0,034	0,279	0,414	0,567	0,115	-0,334	0,211
SK	0,304	0,136	0,263	0,277	0,046	0,061	-0,326	0,224
SL	0,259	0,556	-0,001	-0,025	0,162	0,060	0,052	0,182
BG	0,110	0,655	-0,232	0,418	0,341	-0,063	-0,248	0,164
RO	0,020	0,302	0,066	0,214	0,557	0,158	-0,179	0,099
HR	0,061	0,426	0,129	0,145	0,065	0,069	-0,730	0,123

Grey colour reveals that the impact of variable on PT usage was significant $p<0,05$

Many studies have shown that frequency and reliability is an important attribute for the satisfaction of public transport users (Chakrabarti and Giuliano, 2015; Efthymiou and Antoniou, 2017; Irtema et al., 2018; Ngoc et al., 2017), and is very important for journey time and interchanges (Redman et al., 2013, Chowdhury and Ceder, 2016; Jenelius, 2018). Comfort and safety are important factor in determining travel and PT service satisfaction as well (Dell'olio et al., 2011; Le-Klähn et al., 2014; Şimşekoğlu et al 2015; Ngoc et al., 2017; Irtema et al., 2018; Mugion et al., 2018; Chica-Olmo et; 2018). However, in our case, frequency and reliability as well as comfort and safety only in third of EU countries (in 7 from 21 countries) significantly influenced the PT usage. This could be related to the fact that the travel mode use could be considered as a habitual behaviour and is carried out automatically without deliberate thinking due to repeated use (Chen and Chao, 2011; Şimşekoğlu et al 2015; Mugion et al., 2018). Dissatisfied captive passengers have no transport alternatives and no way of expressing their dissatisfaction with these services other than complaining (Mouwen 2015).

Facilities at the stop were even less significant. The amenities of stop and station significantly affected PT usage only in five EU countries, particularly Ireland, Slovenia, Slovakia, Poland and Estonia. According to the other authors' findings, the condition of stations or stops is identified as the most influential factor affecting the overall satisfaction level with public transport services (Wong et al., 2017; Abenoza et al., 2017) and influences satisfaction with the trip (Friman et al., 2019). Outwater et al. (2011) found that bus stops with modern amenities such as shelters, and seating can significantly affect riders' choice of transportation modes particularly in bad weather conditions (Miao et al., 2019). The European Union has highlighted the need for developing new approaches towards station design (Hoeven and Juchnevic, 2016), however this activity might be effective only in before mentioned countries. Or in the other words, other PT attributes, which determine PT usage more significantly, should be addressed first, or in parallel. Therefore, transport policymakers, mainly on municipality level, should consider what satisfaction categories influence the usage of PT the most in their country. Of course, experiences (like free ridership programmes etc.) of other countries, should be considered before decision making.

5. Conclusions

The promotion of PT usage in EU is one of the main tool to reduce environmental impact, traffic, road accidence, noise level. However, the level of PT usage in EU is rather low and it significantly depend on economic development level. In economically stronger EU countries respondents were less linked to use public transport. It could be related to the affordability of personal car and cheaper cost of PT travel.

The satisfaction levels of frequency and reliability, comfort and safety, amenities of stop and stations and price of tickets differed in EU countries. However, the satisfaction of price of tickets in almost all EU countries was the least.

Analysing the determinants of PT usage, the dissimilar determinants significantly influence the PT usage in different EU countries. In a half of EU countries the satisfaction of ticket price and the distance to nearest stations had significant impact on public transport usage. Meanwhile in one third of EU countries the satisfaction with public transport frequency and reliability and satisfaction with comfort and safety had significant effect on public transport usage and only in five EU countries the amenities of stop and station influence PT usage. These results reveal that improvement of PT service and separate its categories not always may lead to the enhancement of PT usage. Considering that travel mode use could be considered as a habitual behaviour, even dissatisfied captive passengers have no transport alternatives and no way of expressing their dissatisfaction with these services other than complaining. Therefore, it is important to trigger the usage of PT by enhancement the

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image of PT users and incentives for lower car use (higher road, fuel prices, parking charges), as well as awareness rising on health and environmental impacts.

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Design and Consumption

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Adapting Soviet Sustainable Fashion Practices for Circular Economy

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Abstract

This paper seeks fresh perspectives on sustainability practices in circular economy. The inspiration could be found in nations and periods of time where resources were scarce and people had to be creative and inventive to maintain human dignity. The Soviet Union as an all-controlling, pervasive totalitarian state focused the national resources on military development, with little regard for everyday needs of the populace as well as invented the planning economy which collectivism approach destroyed the chains of supply even further. As a consequence of its permanent shortages of consumer products, the state was forcing upon its citizens a regime of austerity and championing them to save the limited resources. The legacy of the Soviet period on sustainability practices and its potential contribution to present/future circular economy has not been sufficiently researched. A lot of different research methods were used in the process. Quantitative and qualitative research and oral history methods were used. To generalize the findings as well as develop a detailed view of the concept both qualitative and quantitative methods were used in triangulation. Different survey methods were used: questionnaires, case studies, structured and semi-structured interviews, semiotic analysis of interviews and visual materials. The reason the research relies heavily on interviews and oral histories is because Soviet-era statistics are notoriously biased and untrustworthy. The picture of everyday life painted by the official sources was quite different from the lived experience of the Soviet regime. Therefore, the research confronts the official stories with personal perspectives. This research also analyses the Soviet-period literature and materials for sustainable fashion practices, highlights the various routes for acquiring the necessary apparel. USSR developed a network of ateliers for repairing, reconstructing, resewing and updating old and worn out clothes, providing workshops, talks, books and classes on the subject in educational facilities. This trove of concepts, ideas, practices, advice, templates, even though produced for a different economy and society, is nonetheless quite astonishing in its scope. By researching and analysing struggles and shortages of planning economy, one could repurpose the forgotten sustainable practices and innovate new ones for the circular economy. Further research should look at the forgotten practices of previous generations. Circular economy is developing in our present abundant yet also precarious society. Even though there exists a seeming overflow of consumer goods, the picture is different if we start looking for longevity, durability, adaptability, timelessness – design characteristics discarded by the fast-cycle fashion industry. Today, our motivations for saving resources and transitioning towards a circular economy are different from the survival instincts of the Soviet era, and one must hope based on a genuine concern for the planetary health and well-being. As next steps, the insights gained through research and analysis should be tested as case studies in practical application to create concepts and prototypes of circular economy product-service systems.

Keywords: Sustainability, Circular Economy, Sustainable Fashion

1. Introduction

A Communist country is a dreamland of socialism – where no one needs money to acquire goods and services. Everybody is equal and has equal rights. All economy is planned centrally and there are no market fluctuations. Everything is owned by the government and the plan is adjusted every 5 years! It was the reality of Soviet fashion industry which was balancing between two realities in parallel universes detached from consumer market and everyday needs. Doing research on the relationship of the Soviet world and fashion one can argue that the fashion accentuates the bipolarity of the Soviet system, as it precisely reflects what is going on in society. On the one hand, there was a fashion world with the 'houses of models' and fashion shows, boutiques, shops, but it existed in magazines, fashion spectacles abroad, and statistical data. On the other hand, private tailors, DIY, ateliers, workshops, movies, forbidden magazines and profiteers made the real living Soviet fashion. Every piece of garment was treasured, especially if it was of reasonable quality. Perhaps this scarcity gave rise to the myth heard from a number of interviewees that 'clothes were more durable in the Soviet era'. They may have been, but not due to superior materials or designs, but due to the lack of alternatives. It was an ideal example of a zero waste society – everything could be useful in the Soviet Union. Soviet citizens were not quick to throw out garbage. When researching the books, articles in magazines and during interviews the outstanding volume of variations and practices stands out. Scarcity of the garments and accessories made people apply creativity and imagination to acquire the requisites. After that, the next problem arose: what to do, when clothing is worn-out, how to manage the winter without boots? To legalize all the underground sewing and repairing activities USSR developed a network of ateliers for repairing, reconstructing, resewing and updating old and worn-out clothes, providing workshops, talks, books and classes on the subject in educational facilities. By researching and analysing these materials, one could adapt the forgotten sustainable practises and innovate new ones for the modern circular economic society. Our motivations for saving resources today are different, and one must hope based on a genuine concern for the planetary health and well-being. Can the tactics of a totalitarian state be recycled and repurposed in today's developed world? What is the role of the designer in fostering new models of production, consumption and lifestyle?

2. Methods

This research takes the form of study and analysis of the Soviet-period literature and materials for do-it-yourself sustainability, as well as interviews with contemporaries. Quantitative and qualitative research and oral history methods are used. Different survey methods are used: questionnaires, structured and semi-structured interviews (Kawamura, 2011). Soviet-era statistics are notoriously biased and untrustworthy. The double standards and propaganda of Soviet Union must be checked with oral narratives to acquire a more complete representation as they both reveal slightly different aspects of the same symbolic reality (Gessen, 2017). The picture of everyday life painted by the official sources was quite different from the lived experience of the Soviet regime. Therefore, the research confronts the official stories with personal perspectives and it was necessary to prove well-known mythological narratives. Another method used in researching for this article is historiography. There were 40 respondents of which 1 was male and 39 female. The aim of the interviews was to obtain evidence about fashion, do-it-yourself ideas and sustainability in the Soviet Union. It all comes down to triangulation (Gaimster, 2011). The research methodology in preparation of this paper included processing and analysis of the relevant literature, peer-reviewed research papers, historical books, databases, photographs, and

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documentaries.

3. Results and Discussion

The basis of planning economy was laid in 1930s during the stage of collectivization and nation-wide industrialization. The principles of planning economy remained invariable till the collapse of Soviet Union (Gronow & Zhuravlev, 2016). Everything is owned by the state and the state distributes and plans for everybody

in 5-year cycle periods (Applebaum, 2012). Figure 1 explains how the Center stays involved in all the stages of production. '*Gosplan'* (National Plan) emerged as a center for thinking and advocacy for rapid, state-led industrialization based on the mobilization of domestic economic resources against the more cautious approach of the State Bank and the Finance Ministry (Feygin, 2019). The economy was planned based on consumer needs and industry abilities to fulfill them. Each level of the hierarchy would be assigned assets and then tasked with meeting output goals by using them within a five-year and one-year framework (Feygin, 2019). In light industry

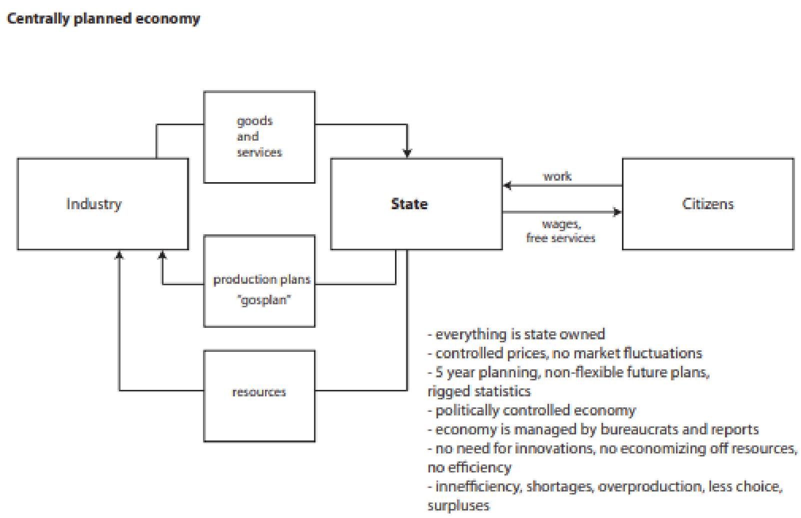

***Figure 1**. Centrally planned economy scheme*

the demand for apparel was rising especially in the post-war years (Gronow & Zhuravlev, 2016). It was decided to develop new guidelines for the sector of light industry. "Mass production should have repeated the appearance of luxury prototypes as seen in Soviet fashion magazines" (Bartlett, 2010). Nevertheless, the mass production was struggling till the end of 1960s because of its "incapability to satisfy the basic needs of citizens" (Tihomirova, 2015). The ideal of mass production was very simple: the best fashion designers from Soviet fashion houses working to create the best garment designs. Packages of finished designs would include patterns, sizing, technical specifications, desired fabrics, buttons and fittings, which would be transferred to production factories fulfilling government orders to promptly supply the USSR with modern clothing (Figure 2). Government-controlled light industry would quickly eradicate old and threadbare garments, and the Soviet citizen would permanently show off in new, fashionable designer clothes. Soviet government would monitor citizens' style to become more politically correct, predictable, close to an aesthetical perfection, medicinally and climatically suitable and convenient. "It would completely eradicate the desire for the fashion beyond the

Iron Curtain" (Bartlett, 2010). This ideal model for fashion mass production failed due to different reasons and circumstances. Houses of models were supposed to be "financed by mass-production industry commissioning and purchasing designs, but instead, sewing factories opted for production from existing well-known pre-war patterns or own designs reproducing outdated and low-quality apparel" (Lebina, 2015). Fashion houses operated with losses by offering the designs to factories for free, which later were used as inspiration for altering pre-war patterns 'to customize templates according to the requirements of contemporary fashion'. The production of apparel underwent a lot of 'substitutions' affecting the quality.

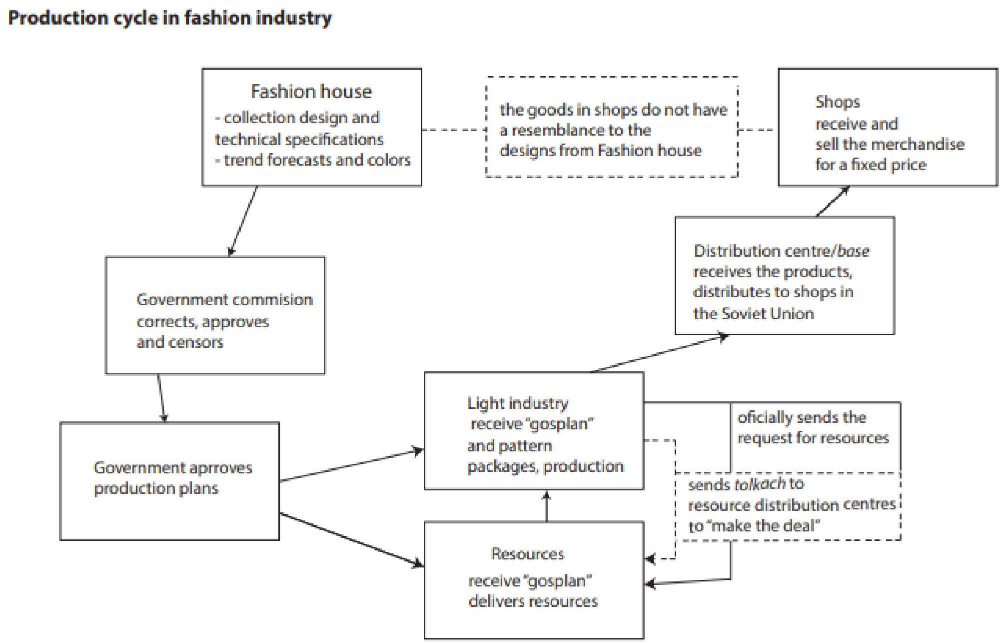

***Figure 2**. Production cycle of garments*

As seen in Figure 2 the garment that reached the distribution centres was reproduced in "a hundred thousand copies and shared almost nothing with the fashion drawing or with the prototype designed for the textile company by the house of models" (Bartlett, 2010). It turned out that constructing and developing specifications was one thing; it was entirely another level of complexity to tackle the production of the non-altered prototype. When working for production requirements, the design process was strictly regulated: even the exact amount of threads and fabric was calculated to the last millimetre. Designers should be aware of the complexity of the prototype production process. Production technology significantly limited the artist's creative ideas, as even the "slightest deviation from fixed standards was not acceptable" (Priedola, 2017). "Fashion actually did not exist in the Soviet Union" (Huber, 2015) or if it did, it never reached the consumer. "Terrible colours and shapes of clothing in shops, an unfortunate measurement system, the eternal deficit of goods" (Stankevica, 2015) – all the problems pointed to that. The houses of models were lacking collaboration partners, the production industry was short of supplies and raw materials, the planning organisation was ineffective and distribution was very tardy. All the affected parties lacked feedback from the consumer: from trading and distribution, to production and to the houses of models. It was decided to develop a collaboration between the 'ateliers of individual tailoring' and the houses of models. The collaboration between those two institutions was forming poorly.

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Ateliers were working under supervision of their own artist's designs, inspired by foreign fashion magazines or individual needs of the clientele; "the guidelines of the house of models were not relevant" (Zaharova, 2007). The ateliers inside the houses of models were an exception: they "developed and produced the collections, organised fashion shows and received individual orders" (Donskaja, 1967). The Soviet citizen visited ateliers quite seldom, only for special occasions; he brought himself the fabric, fittings and buttons; "the design was the result of mutual efforts, and the process was time-consuming" (Maskova, 2015). Thus, "the atelier became a source of fashion trends not controlled by the Soviet government" (Huber, 2015). The individual service in an atelier in Figure 3 looks like a dream come true, especially in the context of a planned scarcity economy. There are several people paying close attention to the customer at hand. The client can discuss their needs and contribute to the design and shape of the garment (Briede, 2015). The lengthiness of the processes is a downside, yet it could be argued that Soviet citizens did have a lot of time on their hands, and the atelier experience was rather enjoyable compared to the rest of the Soviet everyday life. It was a time consuming and expensive process (Adamoviča, 2015). There was variation in

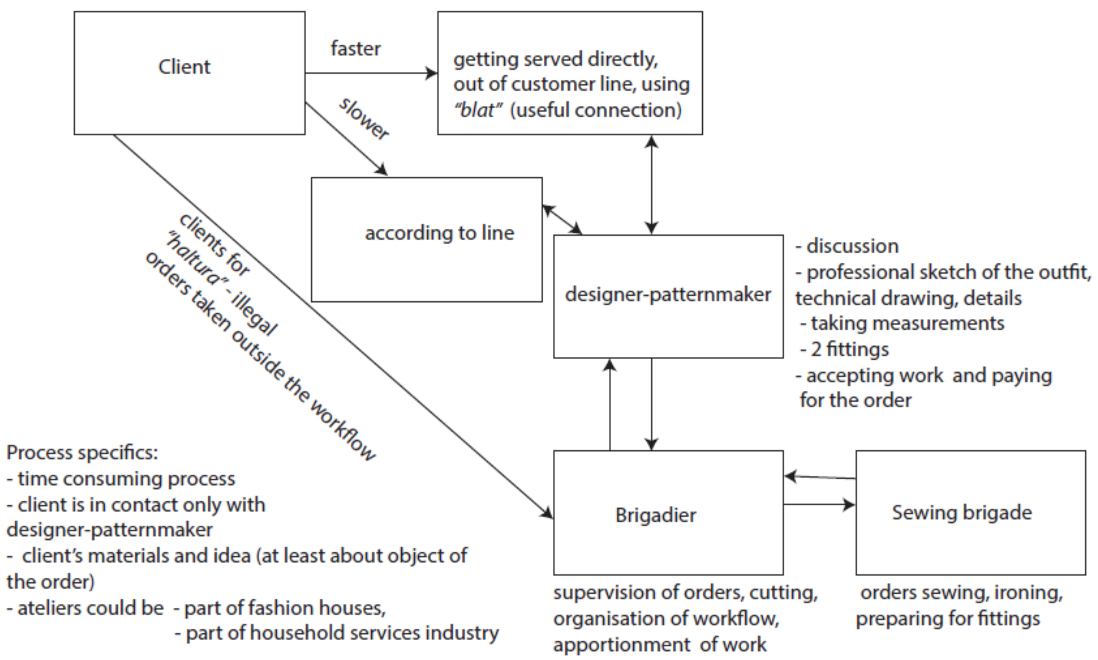

Figure 3. *Service process in an atelier*

the result of the process, depending on the client having the right connections to procure the best fabrics – a 'deficit' item in the USSR, as well as to have access to the best master, expediated again by '*blat'* and some off- the-books monetary payment. One of the good examples was Riga Fashion House which had not only atelier, but also experimental small scale factory producing only 400 pieces of trendy and high quality garments per month (Smeltere, 2019). As indicated in Table 1 there were special repairing and upcycling ateliers specialized in sewing "a new garment from two or more used ones, or from a combination of what was available"

(Redina, 2015), “make a two-piece costume from an old coat, or a garment made from re-sewing the inside out” (Gotsouliak, 2015). Before remodelling the existing garment additional manipulations were necessary – laying out, taking apart, cleaning, hydrothermal processing (Smirnova, 1979).

Table 1. *Techniques to prolong the duration of garments and accessories.*

Category	Problem	Where it was solved	Workshops
Footwear	- prophylaxis, finish and reconstruction for soles, replacing high heels - stretching - replacing the heels and soles - zipper, inner parts and insoles replacement - replacing or dyeing, restoring the coating	- workshop - at home	- shoe repair workshop - atelier
Clothing	- re-sewing - mending - tucking - replacing worn-out details and garment parts - re-sewing garment inside out - replacing the lining - dyeing, toning - zipper replacement - button-up fly replacement - fur repairing - fur garment re-sewing - knitwear repairing - individual knitwear orders	- workshop - at home - with the help of friends or relatives	- ateliers, - re-sewing and repairing workshops, - household services *combinat* (centre) - fur and leather workshops, - individual knitwear workshops

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Bags, accessories	**umbrellas** repairing frame, automatic opening **bags** zipper replacement, replacement or repairing handles and locks, replacing the lining, dyeing, patching up **hats** mending, repairing, dyeing, re-coating, replacing the lining, ribbon, repairing fasteners	- workshop - at home	- umbrella and bag repairing workshop
Accessories	**jewellery** fastenings repairing and replacing, cleaning **glasses** frame repairing and cleaning, repairing the frames broken in half, replacement of screw, lens and other parts, polishing, cleaning or prophylaxis **watches** repairing or replacing strap, glass, hands; mechanics, clock face repairing	- workshop - at home	- jewellery repairing workshop - optics workshop - watch repairing workshop

Also one could be acquainted with a private sewing master. It was a special process for a special occasion such as evening dress: “greyish-white rough wool fabric long sleeved and closed-cut coat-dress with black spots, metallic belt and brooch” (Stankevica, 2015).

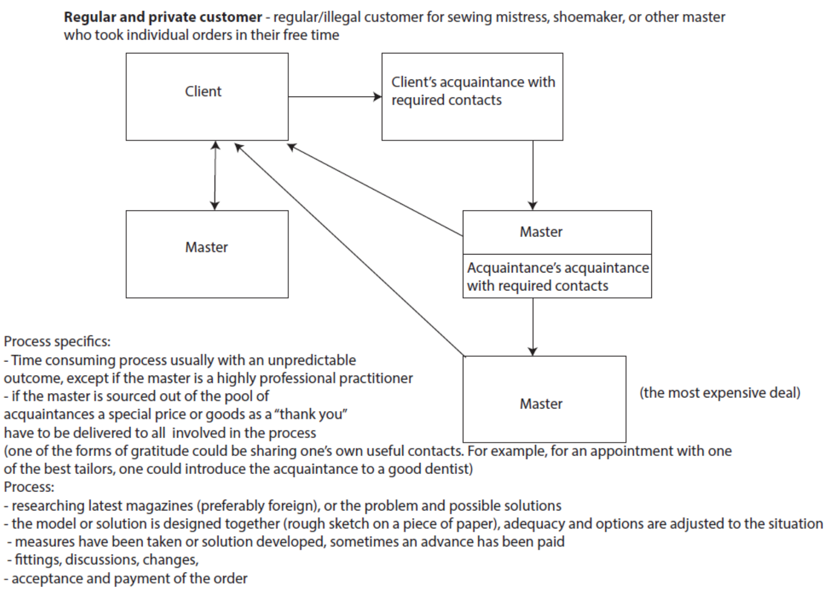

Figure 4*. Service process with a private tailor*

A lot of pre-war individual tailors and designers were practicing underground, some of them worked also in

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theatres, operas, fashion industry (Gronow & Zhuravlev, 2016). It was very hard to get an outside appointment (Figure 4). The practice of sewing themselves or visiting the sewing masters was more widespread in the researched time period than it is today. The tradition to sew clothes themselves belongs to the beginning of the industrialisation and it would be well-founded to assume that in the research period it was declining. In 1950s – 60s sewing was the necessity of life, as undeveloped Soviet economy in post-war time could not manage the rising demand (Zaharova, 2007). A very interesting subject to consider is how the apparel was gathered.

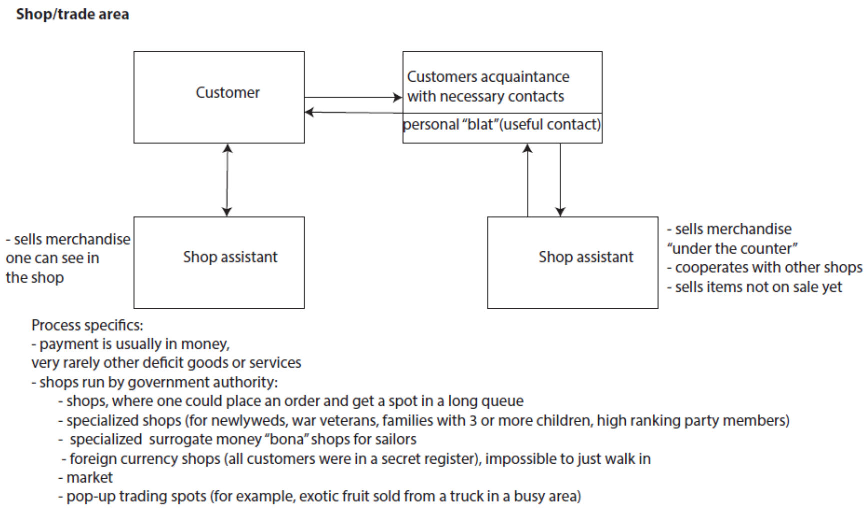

***Figure 5**. Service process of shopping*

It was definitely not easy. One had to be very resourceful and creative to use all the contacts and abilities to do that (Vīcupe, 2018). A Soviet citizen could go to the shop (Figure 5) for food or clothing and realize – the shelves are almost empty, there is nothing one could use. Even then many hours long queues were formed by people in the hope that something to purchase would appear (Smeltere, 2019). Therefore, through desperation and creativity alternative routes to acquire the necessities were made. There were also very interesting shops specialized in family care e.g. for as new-borns, or for newlyweds. One such shop – *Pavasaris* [Springtime] was in Riga, where young couple could obtain deficit merchandise for wedding and first year in marriage, for example – white wedding shoes. The couple could make purchase only once and the official wedding registration permit had to be produced (Gotsouliak, 2015). The other alternative was obtaining goods illegally, and '*speculants'* were severely punished. If operating with foreign currency, the punishment could be death by shooting (Lapenna, 1968). Interesting example of trading goods were through *'bonzhurnaja'* – the floor persons on duty in hotels: one could exchange the desired merchandise from their country (stockings, perfume, food) for money or goods outside the "iron curtain" (Smeltere, 2019). A whole well-coordinated system of illegal entrepreneurship was established, where everyone clearly fulfilled his role and had his own specialization. Cleaners and maids of hotels took only small things from foreigners - perfumes, blouses, ties in exchange mainly for alcoholic beverages. *'Bonzhurnajas'* specialized in larger items such as suits, coats, cloaks, and were also exchanging goods for alcohol or souvenirs. Waiters were engaged in the exchange of large batches of things (for example, a dozen or several dozen cloaks) for large batches of caviar and vodka (and they were not dealing with random foreigners, but by those who deliberately engaged in smuggling). Moreover, the '*speculants'*

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themselves did not sell the items: so the maids handed them over to the senior maids, the senior maids – to the administrator on the floor, the waiters - to the bartenders. Soviet official propaganda portrayed '*speculants'* as unpleasant youths who lounged around hotels, asking foreigners for chewing gum, badges and ties or exchanging them for souvenirs in order to sell them at a speculative price. In reality it was an illegal sale of things of foreign, primarily Western production, which were exchanged for souvenirs from foreigners who came to the USSR or were bought abroad, and then smuggled into the USSR (Veilande, 2017).

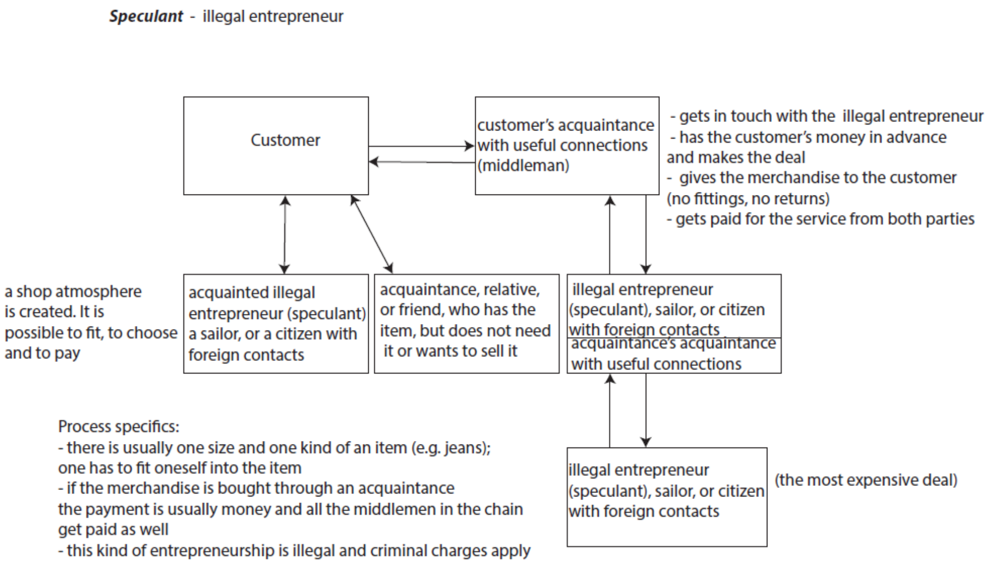

Figure 6. *Service process of shopping illegally*

It was a whole system that was fundamentally different from the image of the '*speculant'* that developed in the public mind under the influence of propaganda. Also there were partially legal ways to sell and buy citizens' goods in government approved commission shops – '*komissionka',* where a citizen sold his valuable personal belongings and shop estimated the value and added on its commission percentage. For the ordinary Soviet citizen it was a place where one could buy used things cheaper than their real cost and in a decent condition or where one could sell for money unnecessary items of furniture, clothing or household appliances.

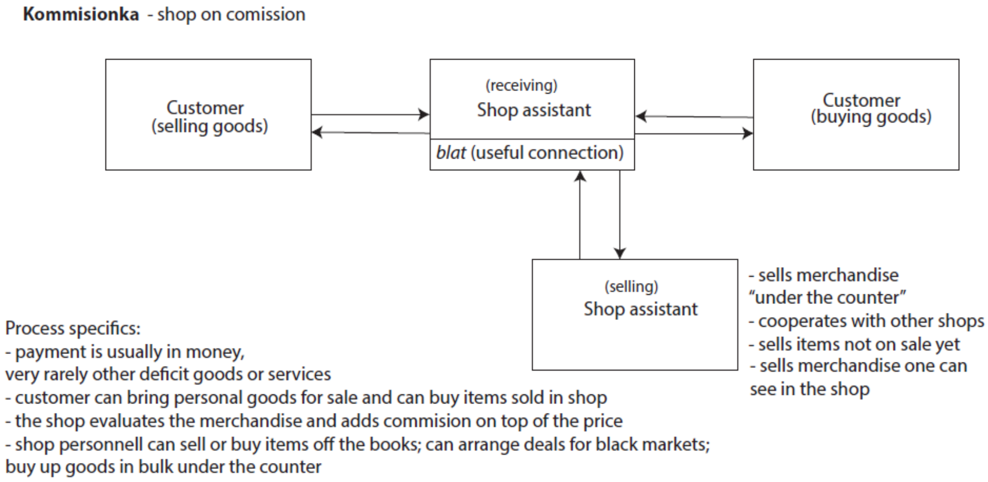

Figure 7. *Service process of shopping in a commission shop*

In reality it was a place where great deal of black market activity was happening. Imported items and various *Grundig*, *Philips*, *Sony* appliances, and other extremely scarce goods went usually ‘left’, sticking under the counter for "friends" or sold way above the price offered by the store to the former owner of the item. There were several other negative aspects of such trade as the sale of things hand-to-hand, that is, without the involvement of the state, selling of stolen goods, payment delays to customers after the sale of their belongings, etc (Tverdjukova, 2013). 1970s came with certain ‘abundance’ of ready-made clothing, and individual sewing and ateliers services started to become more specialized and expensive. Other remarkable up-cycling and re-cycling activities were done at home or with help from private sewing masters. Interview respondents remembered a lot of sustainable and zero-waste activities as gathered in Table 2. It was very common to partially renew the garment in repairing ateliers as in Figure 8 by canting some details, but leaving pockets, the frontal details and plackets intact. Decorative or complementary fabrics were used to make the garment a few sizes bigger or smaller, more up-to- date, or to replace the wilted and outworn collars, cuffs, fastenings and pockets. For example, Mara Kapce in her tutorial for the light industry technical schools teaches how to invisibly mend clothes: “If there is no possibility to make a patch for mending purposes, the artistic mending is the answer. The threads taken out from invisible parts of the garment are used and the mending process repeats the texture and pattern of the cloth precisely. If it is done in very high quality, the mending is practically invisible” (Kapce, 1980)

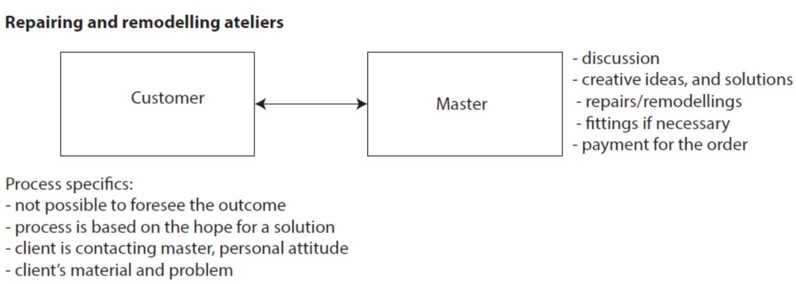

Figure 8. *Service process of repairing in a workshop*

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Also when there were “masters at home” – skilful relatives or friends, they could engage in do-it-yourself (Figure9) activities. The sewing practices were passed on from generation to generation just like “the pre-war Singer sewing machines which became very dear to their users” (Tihomirova, 2015). The houses of models were integrating their creative potential even in the DIY segment by “reproducing elementary models and patterns which were easy to create without specific technologies” (Huber, 2015). The hand-making and DIY field of interest was under supervision of the houses of models. It was the beginning of the distinctive do-it-yourself subculture in Soviet citizens’ everyday life.

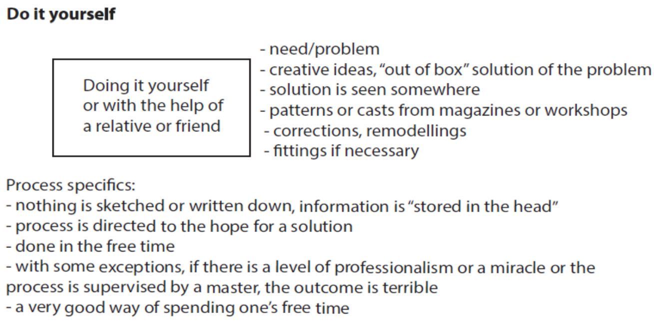

***Figure 9**. Process of do-it-yourself*

People were re-sewing easiest parts of clothing (Gotsouliak, 2018), sewing-in or letting out seams and length (Lubarskaja, 2018), decorated or altered old garments with new appliques, collars, crochets, buttons, laces or frills. Wedges were sewn into armholes of dresses or as decor in trousers, dresses and skirts.

Table 2. *Home practices for resewing, upcycling, or recycling of clothing.*

Resewing	**Remaking**	**Using of scraps and waste**	**Other practices**
- changing the style or length of garment - adding fur trimmings - shortening	- remaking trousers into skirts or shorts - sewing a coat out of blanket - cutting of worn out parts from dresses	**leather scraps can be made into** - wallet - purse, - box,	- re-dyeing - appliques, flowers and other details - artisanal mending, invisible mending
- lengthening - letting in or out, lengthening the garment - combining one garment from two or more outfits - resewing the garment's inside to be wearable on outside - modernizing the pattern - sew-in additional darts, wedges, patches, decorative elements - decorate the edges of garment with ribbon, fur, leather - add new collars, pockets, cuffs, ribbons to old and worn-out outfit - to sew children's	and shirts and adding crocheted and other parts - worn-out and used children's clothing can be remade as cardigan or dress - changing sleeves, cutting off sleeves - making coats or costumes from used army uniforms, or husband's old garments	- eyewear case - appliques - vest - bag - wearable accessories - belt - brooch, - key ring - bracelet - gloves **yarn scraps and waste can be used for** - dress - hat, scarf - gloves - rug - cover - blanket	- invisible mending of nylon stocking with a special mechanism - making hats in looping technique - making flowers from wires and threads - making flowers and leaves from leather - sewing pictures and canvas from buttons - pictures and canvas from leather scraps - leather ribbons - combining leather scraps with old and worn out wearable accessories - printing fabrics -embroidering, dresses, collars, pockets and details

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- to sew children's clothes bigger, with already folded sides and length to be let out if needed - repairing the zipper		- toys - pompom - flowers **knitwear waste can be made into** - cardigan, sweater - dress - children's garments - geometrical ornaments - appliques - hat - scarf **jersey waste** - crocheted curtain	and appliques for dress - totes from sewing together ribbons or garters - crocheted gauzy wool lacey socks, appliques, ribbons, finishes, collars, scarfs, hats and gloves
Resewing	**Remaking**	**Using of scraps and waste**	**Other practices**
		- appliques - macramé, patchwork - making yarn - covers - carpets - napkins, cloths - garments	

When studying the varied models of procuring the necessary fashion goods and services, one cannot avoid noticing the large number or person-to-person interactions required. Be it obtaining ready-to-wear garments or quality fabrics, customized services of a tailor or a highly skilled seamstress, even acquiring materials for repairs, involved a virtual web of social connections and acquaintances. A person's survival and flourishing in the Soviet system was based on this (Smeltere, 2019). Soviet economy was based on relationships as can be seen in Figure
10. The officially approved system was not able to supply all the necessary goods to the society due to fundamental problems of the centrally planned economy. Informal economy sophisticatedly filled the gaps and the relationships emerged organically, grew out of the need. "Western cultures have lost a sense of connection between humanity, place, and nature — but a cultural yearning to reconnect is widespread. The new priority is *relationships*" (Thackara, 2019). There are two types of relationships in fashion – people-to-people and people-to-clothes. In modern society both people-to-people and people-to-clothes relations are weak and consumers are alienated from each other and garments. The informal economic relation bonds in the Soviet Union were very strong, they were cherished, appreciated and cared for, it was like belonging to a secret club (Vīcupe,

2018). In an environment of severely restricted information on global fashion trends and abundance of time to spend to procuring the basic necessities, both the maker and the consumer closely collaborated to produce original, individually tailored and unique garments, using the limited material resources available and involving feats of fantasy and inventiveness. People were hungry for individual style and clothing to oppose the mass production environment (Smeltere, 2019). The same question arises also today. For example, through a more individual, customized or made-to-measure design service a better fit – for both mind and body – can be provided (e.g. Anna Ruohonen) (Niinimäki, 2018). More combinations of people, garments and processes could be designed to enrich the experiences and to add consumer relationships as an essential part of circular fashion today. Some parts of this new more personal fashion system are already emerging (Central Baltic Fashion Seed project, 2017). Good examples of this is the contemporary initiative *Repair Café* (https://repaircafe.org/en/about/), where one of the stated purposes is to strengthen social cohesion by people working on repairing things together. Complex sustainable issues like circular systems need to be approached through a collaborative, experimental and creative mindset to be able to find solutions together. “The only way we will be able to address the important challenges we face today is to do so collectively. Collective creativity can lead to relevant and sustainable innovation” (Sanders, 2015). Fashion is a social construct and a social need. There are consumers who buy new fashion items every week and fashion has become easy entertainment or a kind of fashion “hunt” for some consumers (Niinimäki, 2018).

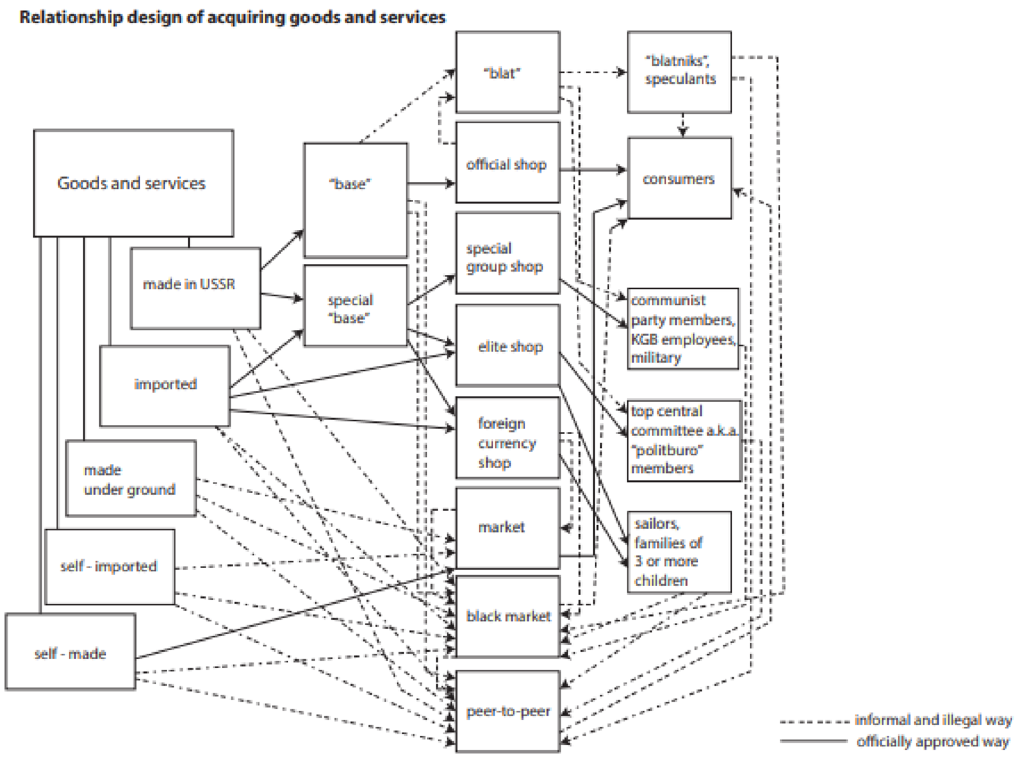

Figure 10*. Consumer relationship interconnections in USSR*

These impulses point to an intrinsic human need of seeing fashion as a kind of adventure, game, a conversation topic, a way to connect with others. This need could be turned around from an ever-faster consumption to a circular consumption pattern by designing a clever system to make circular pattern the object of desire,

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adventure, connecting and sharing with others. The importance and kinds of variations of relationships could be one of the most important lessons from the Soviet Union to be adapted in a closed-loop economy. Technologies can even create social interaction around these activities. Through the help of IT, a community can be built in which new forms of collaboration can happen, even face-to-face. Today's fashion economy is mostly characterized by gaps between the design – done in Western fashion capitals – and making in Third World countries, between the global industry and the local consumer, between the anonymous production and industrialized retail, between the glamorous image of the fashion world and the grim reality of waste, pollution and appalling working conditions of its makers (Berg, Heyn, Rölkens, & Simon, 2018). Today's consumer will not turn back the clock and instantly become master of DIY. For one thing, today's accelerated pace of life does not provide much room for assembling one's wardrobe in ways done in Soviet times – e.g. spending hours on repairing your footwear by yourself ('Наука и Жизнь', 1974). A crucial question is scale: the designers and makers need to produce a certain minimum amount for their business to be viable, while the consumers need to pay a reasonable price to choose the alternative rather than the mainstream fashion system. Contemporary technological solutions and social media networks can play an enabling role here by providing the makers with a global marketplace, but not only that. They are also providing the consumers with global knowledge and understanding of the fashion system, bringing them closer to the people who are designing and making their clothes, be they near or far. Having an honest person-to-person conversation about the origin, production cycle, cost and price of fashion brings to the forefront the questions obscured by the dominant mainstream fast-cycle fashion industry. Author's own designers association *Butterman* is testing and implementing findings in sustainable fashion practices. One of such practices is acquiring very high quality leftover yarns and fabrics from mills in Italy and making timeless collections. The main idea is to construct an adjustable pattern and to produce it in different fabrics. The greatest challenge is to deal with the production companies as the process of adjusting the pattern is time consuming and more expensive than cutting and sewing from a big roll of fabric. Now a minimalistic and more individual approach is used to create high quality garments only in one piece. Malgorzata Koszewska from Lodz University of Technology has elaborated a model to analyse where do waste streams occur in the current circular economy (Koszewska, 2018).

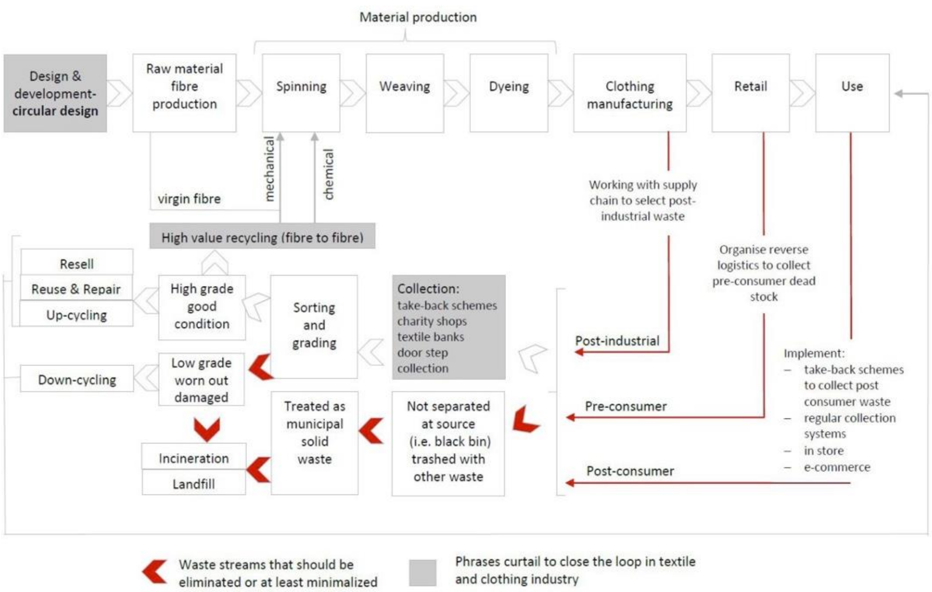

Figure 11. *Koszewska, M. Closing the loop in the textile and clothing industry — a way to zero waste supply chain*

It was used as a framework to analyse the identified Soviet sustainable fashion practices and to suggest where they could be applied to close the circle of the circular economy today.

Phases critical to close the loop in textile and clothing industry:

Phase 1. *Design & development: circular design (Figure 11)*

Soviet sustainable fashion practices were not particularly focused on design and development. In fact, it was the poor product design that often lead to innovation in product alterations and repairs (Lebina, 2015). However, an important aspect of the Soviet practice could be the individual master-to-customer model, where the consumer is closely involved in the design of the product. Even though this practice applied to higher-end, customised products for the fashion conscious, it was popular and wide-spread enough. However, in the medium- to high-end of the clothing spectrum, repairs and resewing are a reasonable proposition. Circularity was not an explicit aspect of fashion design in Soviet times. However, today's designers can incorporate already at the design and development stage aspects of circularity that extend the life and usability of the garment such as: allowing for easy size

alterations along changes in the wearer's body, or to adjust for current fashion trends; facilitating repairs of the garment by providing a "repair kit", instructions or repair service. The elegant and modern garment repair '*Clevercare'* videos by Stella McCartney sustainable luxury brand are rather popular on *YouTube*. It is necessary to give the mending and repairing of clothes a fresh, forward-looking and stylish presence.

Phase 2. *High value recycling: fibre to fibre (Figure 11)*

On consumer level, especially in the scarcity years (1940s-1950s), but also after, this was a Soviet cultural memory and practice (Buravcova, 2015). Consumers were active recyclers of garments to produce other garments; in case of knitwear, it was fibre to fibre: unpicking one knitted garment to make another (Veilande, 2017). However, this was not a Soviet practice on industry level, and it is somewhat difficult to imagine how a consumer practice can be scaled up to an industrial activity. Perhaps such a solution can be a local recycling centre, where consumers can bring their garments to be unpicked and turned into fibre or yarn that can be used to make new items by themselves or by designers. Unpicking activity could become a new form of social interaction. It would be wise to unpick everything even down to buttons and zippers and all of it could be distributed to repairing and upcycling centres and workshops, or returned to factories for reusing.

Phase 3. *Collection: take back schemes; charity shops; textile banks; door-to-door collection (Figure 11)*

Closely related to the above point is the system of collecting pre- or post-consumer products for putting them back into the circular economy. In Soviet fashion practice, such an informal system was working due to the scarcity of products, and probably the entire population was handing down used garments or remodelling ill-fitting or unfashionable items. However, nothing resembling the above-named schemes existed – despite the fact that there were national schemes to collect glass bottles, metal and paper. (Even then the overall Soviet waste management system was quite rudimentary, and consumers often discarded their garbage on the roadside

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or in a forest – some of these dumps existing to this day) Therefore, the way to learn from the Soviet practice here would be to popularise the recirculation of used or surplus fashion as a social practice. This could be done by producing e.g. reality shows in the vain of house remodelling shows. However, we must account for the fact that today's consumers do not usually have the time to remake used clothes, and often would lack the requisite skills. That would be a real waste, because it could boost peoples creativity levels, socializing skills and other benefits of collective creativity. Therefore, this function could be taken over by niche entrepreneurs, such as upcycling shops and brands already existing. Interesting approach to the problem has *Macy's* and *JCPenney's ThreadUp* partnership: where customer can buy and sell high-quality second-hand clothing, to inspire a new generation of shoppers to think of second hand first (Loeb, 2019). Other contemporary practices are e.g. bazaars to trade or sell own clothes for a symbolic amount, or the same facilitated by social media networks, which mirror the Soviet practice but in a more glamourized way, focusing on appreciation of the fashion and personal stories of the garment's owner.

Other phases: *Clothing manufacturing / working with supply chain to select post-industrial waste / post-industrial*

A Soviet practice were "factory shops" operating next to textile/fashion manufacturers, where consumers could purchase leftover fabric or substandard products (Gotsouliak, 2018). These used to be quite popular, and some are existing in an updated form even today. Such shops were an important link in the Soviet consumers' efforts to procure the goods by any means necessary. What may be missing in today's society is the social practice of purchasing surplus fabric and other goods to remake them into new products by consumers themselves. However, the author's own fashion business is based exactly on purchasing fabrics leftover from production cycles at large mills in Italy. (Curiously, the author's design collective *Butterman* is based in the EU country with the lowest textile waste - Latvia, whereas its primary source of raw materials is the one with the highest textile waste - Italy, whose level of wasted textile exceeds Latvia's by a factor of more than 1000 (Koszewska, 2018).)

Retail / organise reverse logistics to collect pre-consumer dead stock / pre-consumer

The Soviet fashion system is hardly an example of collecting pre-consumer dead stock, as it was barely able to produce and distribute any stock in the first place. However, in Soviet times there existed a parallel system of trading goods, which was facilitated by informal actors moving goods from one part of the vast country to another, to supplement the inefficiency of the official supply network. This personal entrepreneurship was flourishing especially in the late Soviet and early post-Soviet years, when wheeler-dealers were working with retail as well as manufacturing to trade unsold goods to parts of USSR with even more scarce supplies. The takeaway for the contemporary fashion system would be to suggest entrepreneurial opportunities to transform unsold/unsellable goods into those in demand. Systems such as "stock shops" exist across Europe. More value could be added to these products by entrepreneurs. There have been experiments such as *Cheap Monday* upcycling its own unsold fashion collection as higher-value items, which sold very well (Halliday, 2018).

Use / implement: take back schemes to collect post-consumer waste, regular collection systems, in store, e-commerce

As discussed above, in the Soviet system there were no such formal systems, but instead a comprehensive informal one (Huber, 2015). Again, if anything could be learnt from the Soviet times, it is to make consumers more mindful of their fashion consumption, and to make re-use of used clothing more socially acceptable like second hand luxury selling platform *TheRealReal* (http://www.therealreal.com).

High grade, good condition; resell; reuse and repair; upcycling

The products upcycled in Soviet times were not designed for circularity, nor were they necessarily of high enough quality to merit upcycling. Even though the interviewees indicate that clothes were durable, it does not mean they were of superior quality, but often just due to being made of die-hard synthetic fabrics – e.g. polyester. Rather, Soviet upcycling practice was due to scarcity: owning one good coat meant it needed to last as long as possible. The biggest gap with today's world lies in the social acceptability and status of those practices. Even in Soviet times, when it was widespread, the reuse of garments was seen as somewhat shameful, an open secret discussed only with trusted friends and family (Vīcupe, 2018). However, the media such as women's or popular science magazines played an enabling role by popularising the various methods of reuse, repair and upcycling. Even though officially there was prosperity and abundance, unofficially the Soviet authorities supported the population in filling the gaps in the supply of fashion.

Low grade, worn out, damaged, downcycling

The Soviet system does not provide much inspiration in the way of industrial downcycling. However, on consumer level it was widely practiced: e.g., an old t-shirt easily became a washing rag, or an old coat became a dog's rug. There was plentiful advice in magazines on how to make these transformations at home. Such practice has fallen out of fashion with the younger consumers, who prefer to throw their worn-out garments in the trash. On the other hand, today's worn out fast-fashion garments are not easily downcycled by the consumer, as it is difficult to imagine what use they could be put to. Perhaps there are opportunities for entrepreneurs to come up with methods to efficiently downcycle consumers' fashion waste, while producing some kind of valuable items from it. Such examples as bags out of plastic bottles already exist. What could be added to it is a person-to-person service, where a consumer's own fashion waste is transformed into a personal useful item for the home, enabled by technology and raised in status by ecological consciousness. The takeaway for today's economy would be again to make popular the methods of prolonging garments' lifecycle, by spreading the message in mainstream media and social networks. Professional services providing these services could emerge as well, as has been the case with some niche products.

4. Conclusions

The Soviet *blat* system in the fashion realm, even though crossing over into the illicit and criminally punishable territory, nevertheless was able to produce a sort of equilibrium to supplement the meagre offering of the official simulacrum of a fashion industry. The fashion-focused consumers who were willing to devote their time and financial resources to acquire fashionable items were able to do so. The skilled masters of customized tailoring and sewing were able to make a living, supplementing their quite basic incomes with extra payments from customers. All these transactions took place within a tight web of social quid pro quo, trading and exchange of information, useful contacts, personal favours, etc.

The Soviet scarcity system unwittingly produced a thriving person-to-person marketplace of things, but also of services, methods, skills. To some extent this marketplace was supported by the Soviet media, such as women

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or popular science magazines where ideas on making or repairing yourself were popularized and exchanged.

There are important takeaway principles derived from the story of rise and fall of the Soviet fashion industry:

1. Mindfulness for the fashion, its provenance and origins;
2. Personal style, originality, customization of fashion;
3. Appreciating the skill of the master;
4. Blurring the line between the producer and the consumer of fashion;
5. Direct communication and co-creation by the consumer and the maker;
6. A web of social interactions and relationships to exchange and trade knowledge, skills, resources, methods;
7. Zero-waste attitude to material resources.

These principles may well be applied in today's fashion economy – in the world of independent designers and labels and experimental fashion cultures. Such an alternative person-to-person fashion system should provide a reasonable livelihood to the producers and value-for-money to the consumers.

A tight collaboration between industry, consumers and academic institutions has to be established to create usable practices and further innovations.

However, repair, adjustment and alteration services are an indispensable part of a sustainable fashion system, of a closed-loop manufacturing-to-consumption cycle. Therefore, existing and emerging fashion brands are well- advised to incorporate these services into their offering.

The Soviet fashion experience gives plentiful examples of all these types of activities. From "commission" shops reselling goods purchased abroad, to an arsenal of methods of repair and reuse, to fashioning new items out of old ones, Soviet times were a true goldmine of sustainable consumption practices.

The research demonstrates that it is useful to cross-check oral narratives with written and visual sources, as they can be biased by propaganda and the transitory nature of memory.

In author's own fashion label experience one could see the rising interest in artisanal "one of a kind" approach to garment design. People are getting tired from fast and unconscious fashion.

More relationship models of people, garments and processes could be designed to enrich the experiences and to place a human being as a central part of circular fashion today.

Caring for, repairing and mending garments could be a creative and satisfying process and one could learn to cherish the belongings by adding personal value and time. The process is very similar to gardening or wild berry picking, or fermenting as opposed to buying vegetables in supermarkets, or running or walking in a forest vs. on a treadmill at a fitness centre.

Terminology

Base – a large warehouse where goods were delivered for distribution to shops

Blat – personal and profitable relationships

Blatnik – consumer with special connections

Bonzhurnaja – floor person on duty in hotels

Gosplan – government approved 5 year plan in centrally planned economy

Haltura – working private illegal jobs in one's free time

Kommisionka – citizen sold his valuable personal belongings and shop taxed the value and added on its commission percentage

Politburo – the executive committee for communist party

Spekulant – illegal entrepreneur

Tolkach – a person with valuable connections, later job position in Soviet companies to make deals with suppliers or customers, who could then use *blat* to help to fulfill the quotas

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From Fish Scales to Sea Jewellery

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Abstract

The development of an identity-based meaningful design considering sustainable products has been widely explored as a theme nowadays, from materials disposals to left overs. This research explores the discard of fish scales to develop jewellery, giving this disposal material a new value. Fish scales were transformed according to Material Driven Design Method (MDD) as an exploratory process which considers material properties, its experiential qualities and materials experience vision, leading to the conceptualization and production of artefacts.

Two techniques were explored: fish scales thermal pressing and fish scales introduction between glass layers, then fused together. These experiences led to two different lines named *Escama* and *Maré*. *Escama* presents a set of earrings using pressed fish scales clusters with no added components, subsequently attached to brass. These pieces reveal the strong fishing tradition that characterizes this fishing town named Matosinhos, through naturally appealing pieces combining the simplicity and delicacy of overlapping fish scale patterns - organic matter stands out for its bright hue and pearly glow. *Maré* shows a technique in which the fish scales are included between two glass plates, fused together along with brass strands. *Maré* jewels combine earrings and pendants composed by discarded glass pieces exhibiting these fish scales as exquisite silvery elements. This set of jewels proposes a new life for a surplus material, enhancing its aesthetic qualities through the glass translucency and blue hues. Each one of these pieces bring us Portuguese sea waters through the sophistication of a jewel. Both lines present a new perspective using an underestimated material whose lifespan is now extended, moving towards a sustainable economy; reaching a greater poetic dimension.

This research was developed under We Won't Waste You, a research project held in Design Studio FEUP, exploring and transforming different waste materials into new raw materials. The creation of the referred jewellery pieces took place in academic context, in response to a proposal in Master in Product and Industrial Design, held at the Faculty of Fine Arts (FBAUP) and the Faculty of Engineering (FEUP), from University of Porto. Investigation and product development evolved in collaboration with Matosinhos City Council, for Oficina design, a socially inclusive project driving the creation of sustainable and innovative products inspired by this municipality. A detailed explanation will be carried out through context and research outlining relevant phases of the project development.

Keywords: Fish Scales, Jewellery, Eco-Design, Sustainability, Collagen

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1. Introduction

The debate on Global Warming is now more relevant than ever, and the main responsible for all its consequences is the human being, as stated by the global scientific community:

> *"According to the World Bank, 3.5 million tons of solid waste were produced globally per day in 2013, and by 2025 this number could reach 6 million. In Portugal alone, 13,616 tons of solid waste were produced per day in 2012, and this number should reach 15,886 by 2025."* (Fernandes et al., 2018).

It is urgent to preserve the world we live in, while taking care of the future generations. In fact, discussing environmental damage has changed design, extending it to a new category of products which try to prevent it. (Clementino and Arruda, 2018):

> *"Design for sustainability is not necessarily a new subject. Research and studies about it rapidly increase, given the current conditions of the planet and the way lifestyles, production and consumption continually move towards unsustainability."* (Fernandes et al., 2019).

The fashion industry is a major contributor to problems such as resource depletion and environmental pollution. Speaking of the jewellery industry specifically, it is known that its biggest impact lies on carbon dioxide emissions (CO_2), generated by the mining of precious stones and metals, as well as mineral processing and manufacturing. Action is needed to avoid catastrophic scenarios and irreversible damage to the planet - and jewellery has a role to play in this. It is true that this is a small industry compared to several others, however, proportionally jewels' components imply higher carbon emissions in comparison to many other everyday artefacts production. Thus, although we are speaking of a smaller scale of production when compared to the whole fashion sector - whose main consequences are related to textile handling processes - it is relevant to reflect on the impact of simply acquiring a jewel. (Walker, 2019). Despite this unfortunate scenario which we are currently facing, it is necessary to look at it as an opportunity to promote the conscious purchase of fashion accessories, which can have a surprisingly positive impact:

> *"(...) Sustainable Design has been highlighted as an important factor in breaking paradigms and changing behaviour."* (Chaves, 2018).

Environmental impact mitigation tactics in jewellery production processes (such as responsible exploitation of mines and metal reuse) is becoming a common procedure among multiple companies. This attitude responds to an emerging market segment, made up of consumers who are aware of the inevitable consequences their actions may have on the environment.

> *"Whether due to environmental consequences or the increase of society's policies and pressures, the environment and the concern for sustainability have taken up space in organizational discussions and practices."* (Casas, 2019).

In Project Design classes (Master in Product and Industrial Design - 2018/2019) students got to deal with constant development of several products, while being in touch with different areas, which contributes to a broader experience. It was possible to take advantage of being in the Faculty of Engineering, where different disciplines contributed to the proposal development following integrated project design methods.

Design is essentially interdisciplinary, especially as it involves both producing and applying knowledge. It is permanently in search of comprehensive answers alongside with manifest evolution in science and technology, an idea that goes against its understanding as a purely aesthetic discipline. (Gomes et al., 2018). Interdisciplinarity, intrinsically related to the idea of holistic thinking, is deeply connected to an individual's receptivity to contributions from several different areas of knowledge, leading to a broader understanding of the surrounding reality. (Fontoura, 2011):

> *"Knowledge is no longer organized into different shelves, and all disciplines have to contribute to the efficiency of the product."* (Fernandes et al., 2018).

Product development is inseparable from areas such as design, engineering and ergonomics: it is certainly favoured when various areas of knowledge meet and contribute together transferring methods and breaking boundaries among them, in order to reach a product solution validated by their criteria. This method enhances lateral thinking, leading to an optimization of student preparation as well as more concrete and deeper responses to artefact development. (Gomes et al., 2018).

In this course's first year, Project Design carried the challenge of (re)inventing new materials. Students had to identify a waste material and a method to transform it in a raw material while proposing a product made through low tech production systems. Sea Jewellery arises as one of many responses to the briefing introduced by We Won't Waste You (WWWY), in a partnership between Porto University and the City Council of Matosinhos: students were asked to conceive design artefacts inspired by Matosinhos and made out of its wasted materials. Main constraints can be identified regarding the fact that:

> *"(...) proposals had to be made with lowtech productions systems that could be developed by a socially vulnerable group of unemployed active adults identified by the social-care of Matosinhos."* (Fernandes et al., 2018).

The projects developed and presented by different groups were very different, each one of them highlighting different problems and features, from eggshells to wasted coffee powder or plastic cups. Product development was guided by a proposed methodology considering a specific sequence of steps to be mentioned next. First stage consisted in visiting Matosinhos, followed by getting to know its people and its culture, giving it context and moving towards its identity. Passing through Matosinhos, it was possible to understand that fish scales were thrown away every day; fish scales were then explored through theoretical and practical research, because it was understood that they were appealing and very different depending on the type of fish, while representing this council as their perception is strongly connected to the sea. The Material Driven Design methodology (MDD) was followed, as it focuses on exploring material perception according to different dimensions, influencing the perception of a product. After making a survey, it was possible to understand that fish scales had a big potential, especially in what comes to its aesthetic qualities, which influenced the decision of creating a set of jewels. After that stage several experiences with different materials were made and carefully analysed and two techniques were selected for proposing different jewels. It was later sought to validate prototypes through an online survey.

Sea Jewellery, to be exposed in detail throughout this document, foresees a set of artefacts inspired by this

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Portuguese fishing town named Matosinhos, reflecting its identity and considering social design with an environmental purpose. In it underlies the inherent process from collecting the fish scales until the creation of prototypes using surplus materials and extending their life cycle. After theoretical extensive research, it was possible to develop a set of experiences and propose a product which responds to a social, environmental and innovation concern through the development of new materials. These jewels do not intend to incorporate precious stones; instead, through these two collections it was possible to overcome the challenge of creating meaningful products through transforming discarded surplus materials into valuable artefacts, placing the consumer at the beginning of each process.

> *"(...) the contact with current global problems such as sustainability and social vulnerability, and development of a social conscience that goes beyond academic scopes, understanding the social responsibility that a designer, as a professional, has in the community and the environment."* (Fernandes et al., 2018).

This investigation was driven by the belief that it could represent one step towards the mission of contributing to life quality improvement and preserving the planet:

> *"It is known that design has expanded its borders and has been acquiring a broader, systemic and humanistic form over the last decades. A design driven to meet society's real needs has been growing on debates, research and actions in this field of knowledge; in addition to a greater awareness of the designers, who must assume their role as transforming agents of society."* (Melo and Engler, 2019).

2. Methods

The proposed methodology to develop this challenge was based on Project Based Learning and Material Driven Design methodologies. A series of steps that followed a specific order (although there always was a link between them all) namely visiting Matosinhos, studying its culture and its people, analysing waste disposal, doing bibliographic research, exploring material experience and proposing a product. Subsequently, it was sought to validate the obtained results.

The first phase included visiting Matosinhos, the place where all questioning, reflections, research and ideas would converge. Matosinhos was subject of reflection having in mind a strong connection with the Atlantic waters, considering its people and its neighbourhood relationship with Porto as a major urban area. Walking through its streets, squares and beaches has helped creating a set of references, which somehow came to be key ideas to define its identity as a place: it permitted collecting manifold elements such as signs, words, images, shapes, patterns, textures, metaphors, historical elements and habits. It is easy to find this coastal city very appealing for its dynamics, alongside with its environment, history, culture, sports and gastronomy. Here lies a strong iconographic world, which of course includes the fishing tradition, in a place where land meets sea.

> *"The beaches and the sea are not only a recreational space but also an important source of raw materials with great impact in the economic development of the city."* (Fernandes et al., 2018).

It was tried to understand more about its people, including those who live and visit this place. Their habits were analysed, as well as the contributions left by those who lived or left a mark in this remarkable place.

It took a closer look to come across the extraction of waste in the process of cleaning fish before sale. Fish scales, among other components, were daily discarded in fishmongers (Figure 1) and fish markets. Along product development a constant research was done, based on collecting data through bibliographical and web research; the selection of discarded fish scales as the main material for the pieces to be designed was followed by its careful observation and exposal to several tests, production of surveys, photographic records and informal interviews.

***Figure 1**. Fish for sale in a local fishmonger.*

Material Driven Design methodology (MDD) was truly relevant at this stage in that it allowed product development to unfold around the material that would constitute the artefact to be made. In this sense, fish scales were explored according to the various dimensions that can be associated with them.

> *"In search of a proper application through such an understanding, material scientists and industries have reached out to designers to guide the development of materials by experiential goals."* (Karana et al., 2015).

It was of main interest to explore the perception of fish scales by the public in general, which led to an inquiry headed to a small sample (a total of 32 received answers from respondents), due to an initial stage. It was sought to understand the first concepts coming to somebody's mind when confronted with this subject; to what ideas the material induces, the type of activities or other materials associated with it, the sensations it awakens, the attributes that best characterize it, as well as which other characteristics may be associated with it. The analysis of results allowed awareness of most relevant characteristics in fish scales, reflecting on their strengths (aesthetic qualities such as brightness, translucency, delicacy), as well as aspects to be improved (fragility, strangeness, bad odour). This research was driven by the idea that a material will always change a product's perception, as materials carry in themselves specific signs and values. (Karana et al., 2015). After collecting and analysing all answers it was agreed that it would be of great interest to design a set of jewels.

> *"The 'material' should also elicit meaningful user experiences in and beyond its utilitarian assessment. This requires qualifying the material not only for what it is, but also for what it does, what it expresses to us, what it elicits from us, and what it makes us do."* (Karana et al., 2015).

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Figure 2. *Dried fish scales after cleansing with running water.*

The fish scales' aesthetic (see Figure 2) took an important part in its choice. These elements combine brightness, translucency and several silvery hues which may right away be connoted as attractive features. As it is known they surround the fish's skin, coating its body, standing out and overlapping throughout its volume:

"The integument forms an external protective structure parallel to the internal endoskeleton and serves as the boundary between the fish and the external environment." (Helfman et al., 1997).

Scales are regenerable and a means of protection, simultaneously storing calcium. These elements constitute an important part on the fish's basic functions, such as its hydrodynamics. Initially it was sought to understand these scales considering their physical and mechanical properties. As a mineralized tissue, a scale's microstructure is composed of a network of collagen fibbers, which supports a mineral matrix. This kind of material doesn't have uniform properties or appearance, but the combination of considerable strength and toughness with low density and attractive appearance make it rather interesting to explore. Plus, fish scales may have multiple sizes, patterns, colours and textures, depending on the type of fish and on their location in its body. (Sudo et al., 2002).

A research was made in order to know what has already been done out of this material: it was understood that information regarding different ways of processing or transforming the material is scarce (except that of Erik de Laurens, to be explained right away). Several artefacts regarding a traditional process were found. These objects are composed by previously washed fish scales, juxtaposed to one another, emphasizing its perception as a handcrafted product. Erik de Laurens was especially relevant as a reference for this process. Graduate in Royal College of Arts, Laurens questions the industry through his work, promoting creative and alternative solutions. He mainly cares about an extensive exploration of the animal kingdom and processes of production. In *The Fish Feast* (Figure 3), de Laurens develops a surprising material, composed of fish scales after being exposed to heat and pressure, without any kind of exterior binder:

"Its natural structure means that it is surprisingly strong and easy to dye in a range of colours. Eriks next aim is to develop further products and opportunities that can be used to sustain local fishing communities." (Lefteri, 2014).

Figure 3. *The fish feast, Erik de Laurens (detail).*

The process of cleaning and drying these scales extinguished any unwanted odour, simply depending on washing them under running water. The next step was to try and develop different materials from those available in the market, from alternative raw materials, in response to the manifest environmental concern that

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stands before the unfortunate scenario which we are facing. This organic material's behaviour was object of study when coupled to several others - an experimental research looking for the enhancement of its appealing qualities, strongly influenced by MDD. A set of experiments were carried out with discarded fish scales. These experiments aimed to create new languages and ways of communicating this wasted material of great potential, while adequately applying it on prototypes.

Initially, fish scale staining tests were performed using natural products to change the original colour of this material. These tests consisted of dipping a sample of scales into red wine, and different kinds of infusions. After naturally drying them, it was observed that fish scales acquired the colour of the liquids in which they were previously submerged, still showing some translucency. Since one of the characteristics that best defines this material is its light hues, it was decided to keep its natural colour, allowing its easy recognition.

It was first decided that fish scales should be recognizable in the prototypes to be produced, which has led to searching for translucent or transparent materials that could eventually complement fish scales. Using CES EduPack 2018 level 2 database it was possible to access a graphic combining Transparency and Price (EUR/kg) as variables. Only transparent materials were then selected, as shown in Figure 4.

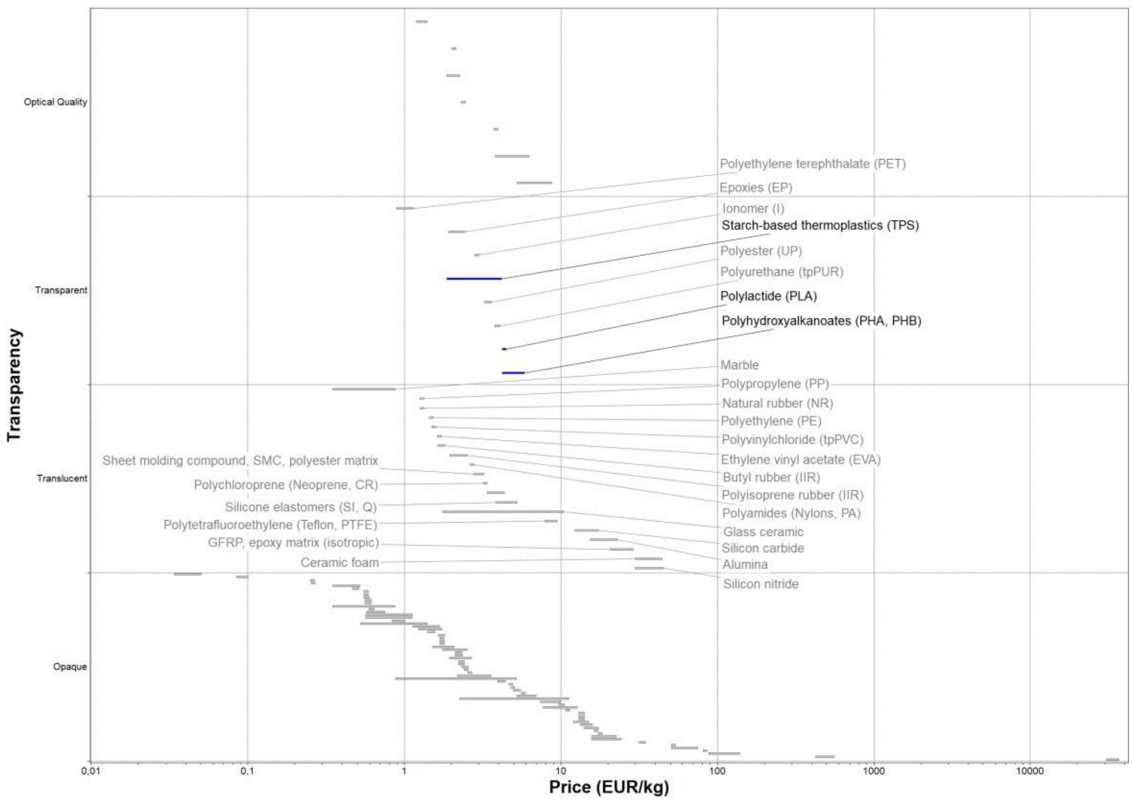

***Figure 4**. CES EduPack 2018: Relating Transparent materials with Price.*

From that moment on, tests were performed using wasted disposable Polyethylene terephthalate (PET) cups. These tests consisted on placing cups lying inside an oven, introducing the scales in their empty spaces. When exposed to high temperatures, PET surfaces came together, keeping their transparency. Once the samples were removed it was possible to verify that one could see the scales inside the transparent material, however, these scales would suffer deformation making it difficult to identify those elements.

As it was hoped that the process of transformation of this material would be as sustainable as possible, in addition

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to previously applied restrictions, biodegradability was added as a requirement. By analysing the materials which met these conditions, Starch-Based Thermoplastics (TPS) have been discarded because they dissolve in water, as it was intended to create a lasting product. Polyhydroxyalkanoates (PHA and PHB) were also discarded since, despite often being used in packaging, the information regarding this material was considered scarce.

Testing with Lactic Polyacid (PLA) was performed as it is a commonly used material in 3D printing, which could eventually be valuable for product development. Granulated PLA was used, with which 3 different samples were obtained. Whether fish scales were put separately on a silicone mould, then pouring PLA over it, or a mixture of both was poured directly, the obtained results were not good enough. In all experiences it was seen that scales

seem to have buckled when exposed to heat, again losing their original shape.

After that the software (level 3 database) was also used to find a material with a lower melting point (Figure 5). Chosen conditions were again transparency or translucency and also biodegradability. Polycaprolactone (PCL) was obtained as an alternative material to PLA. Although this material has a lower melting point, the PCL has a translucency, whitish colour appearance which is why it was not used.

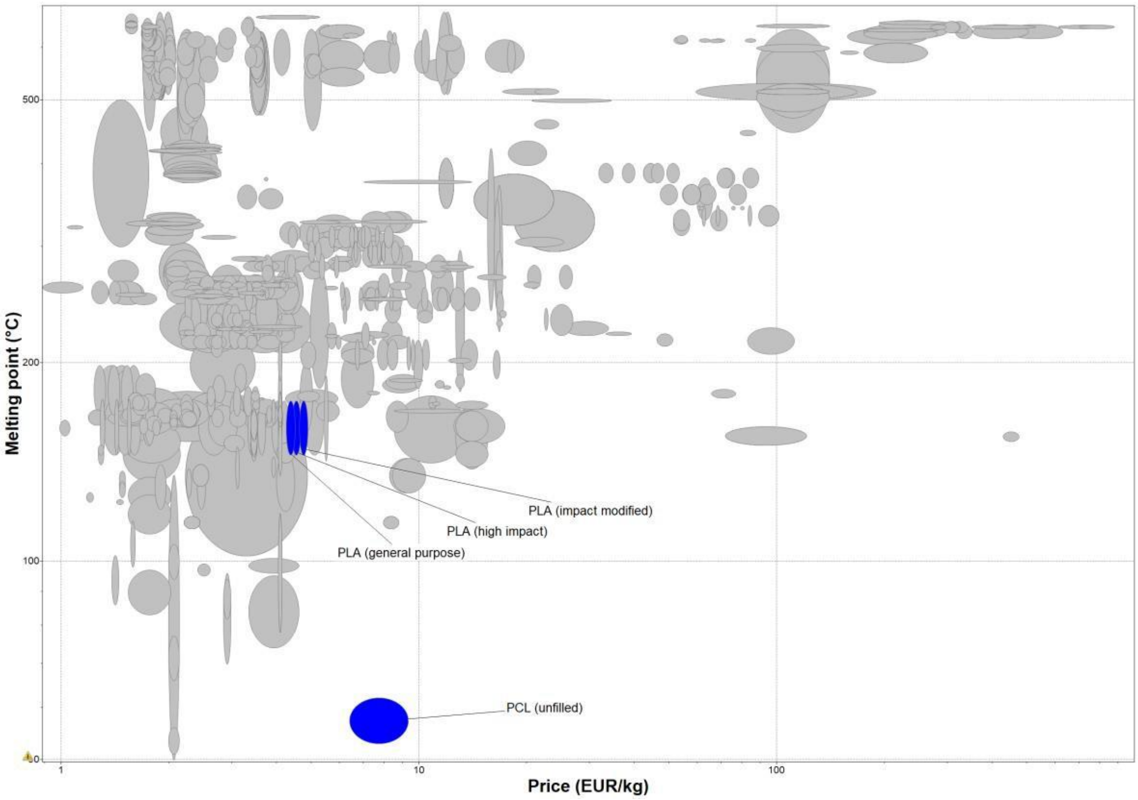

Figure 5*. CES EduPack 2018: Relating transparent biodegradable materials' Melting point with Price.*

All results were analysed, and two different techniques that best conveyed the aesthetic qualities of fish scales were selected, allowing them to remain recognizable through the contemplation and handling of these jewels. These two techniques, developed to conceive Escama and Maré (Portuguese words meaning *Scale* and *Tide*, respectively), are applied to jewellery prototyping, as it is shown next.

2.1 Creating *Escama* - Fish scales' Thermal pressing

Early experiments with the thermal pressing method were inspired by the work of Erik de Laurens. Since the information about this process was scarce, it was necessary to perform several tests to obtain a cluster of scales without adding any synthetic materials. Initially a sample of scales was placed between two sheets of parchment paper and pressed using an electric iron. Then it was tried to expose scales to high temperatures, using a kiln, placing them inside a closed mould or between metal plates, exerting pressure through high density objects placed on its top. The obtained results were disappointing, since the scales became dry and did not agglomerate.

As soon as it was possible to use a thermal press, several samples were produced. Variables such as pressure conditions, temperature and exposure time were explored. Initially a temperature of 100 ºC was used as indicated by Erik de Laurens' process information, closing the press for 10 minutes. Through this test it was found that collagen spread in the places with bigger amount of fish scales, producing a slightly darker stain. It is believed, due to the observation of similar processes regarding fish scales' thermal pressing, that collagen acts as a binder in this process. Several other tests followed this one, but results were not satisfying as scales were getting drier, gradually shrinking, therefore losing their original shapes.

After a set of experiments, it was possible to arrive at several constraints that allowed to obtain several blocks of pressed fish scales taking advantage of their natural tones and without crushing them. Fish scales were compressed through a hydraulic press, combining pressure and thermal regulation. Previously washed scales are evenly distributed on a 40x40cm Teflon coated steel plate (Figure 6), positioned on the press' lower plate, and the set is arranged on top of it. The plate is positioned inside the press, as shown in Figure 7, followed by an additional one. A reasonably concentrated portion of overlapping scales should be placed as it will spread when pressured between two plates. Once this step is completed, an extra thermocouple is placed close to the previously heated fish scales to ensure that those will reach an adequate temperature. Compression between plates occurs taking an upward direction. Once the plates are closed, the desired pressure and temperature values are set using PID temperature controls, as well as precision regulators and press controls.

Figure 6*. Arranging a fish scales set on the plate's surface.*

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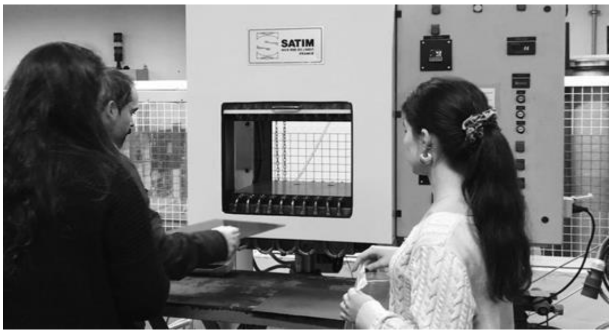

Figure 7*. Placement of steel plates in the thermal press.*

To achieve an efficient result, a 25 bar pressure should be applied, as well as simultaneously submitting the material to 130 °C, which precedes the cooling cycle. After a 10 minutes stage, the equipment controls are used to start cooling the press plates. As soon as the press reaches the maximum temperature of 60 °C, pressure decreases until the lower plate moves away. The added plates (positioned over the machine's lower plate) are then removed from the thermal press and separated from each other; the assembly is carefully removed, and the desired result is obtained (see figures 8 and 9). It is then necessary to cut out or break the agglomerate: cutting or breaking this material will simply depend on the desired finish for each specific product. Fish scale clusters were later coupled to standard jewellery pieces.

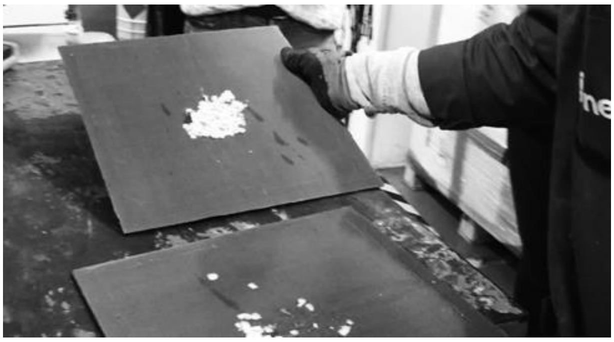

Figure 8*. Dishes are carefully separated from each other.*

Figure 9*. Material clusters removal using a spatula.*

Thermally pressing fish scales was a surprising process as it has shown the possibility of creating scale agglomerates without the use of any synthetic binders. As for the conceived products, their connection to other elements that allow their usability as jewellery are yet to be developed. In this case standard jewellery components were added to pressed scales clusters using cyanoacrylate (superglue). This connection is durable, impact and water resistant, but it is not recyclable nor biodegradable, which should be changed in future development.

Producing pieces for this jewellery line involves specialized machinery and is relatively simple and fast, which makes prototyping easier. It requires knowledge on handling hydraulic press controls. Using a smaller heat press will reduce the energy impact of creating these jewels. Fish scales are easily perceived when looking at these clusters, since their shape remains practically unchanged, as well as their tone and brightness, allowing to foresee a random and disordered arrangement between the various elements. The recreated material is therefore able to communicate these products while highlighting fish scales' natural origin and organicity through a delicate appearance. The fact that the scale agglomerates do not have any type of external binder, as mentioned above, is truly important for this technique, making it a 100% natural and biodegradable material.

On the other hand, it is very difficult to predict the final result as at the moment of pressure between metal plates scales can be pushed apart creating fragile areas with less amount of scales, which makes these elements brittle.

2.2 Creating *Maré* - Fused glass with fish scales

An experience combining translucent glass and fish scales came to be positively surprising (see Figure 10). Small pieces of float glass to be discarded were found in a glass workshop and kept for producing several small-scale experiences. Scales were put between two glass plates (of 6x6cm each), then fused together. The result is an appealing and intriguing complex of small elements with silvery nuances.

***Figure 10**. Fused glass plates with fish scales in between.*

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Given the decision to design a set of jewellery pieces, it was sought to find a material to enable its usability and incorporation. Again, level 2 database CES EduPack was used to find a material which would resist to 710 ºC, which was defined as the maximum temperature to which the glass had to be exposed in order to be joined. As seen in figure 11, Melting point (ºC) was related to Price (EUR/kg). A melting temperature above 710 ºC was set as a requirement, and the group of Metals and Alloys was selected. After analysing the different kinds of materials meeting the described restrictions, brass was chosen. Besides having a melting point between 882 ºC and 967 ºC, this material has a soft golden hue that was considered an aesthetically interesting feature. In addition, this is a low-cost, corrosion resistant material that can easily be welded or machined.

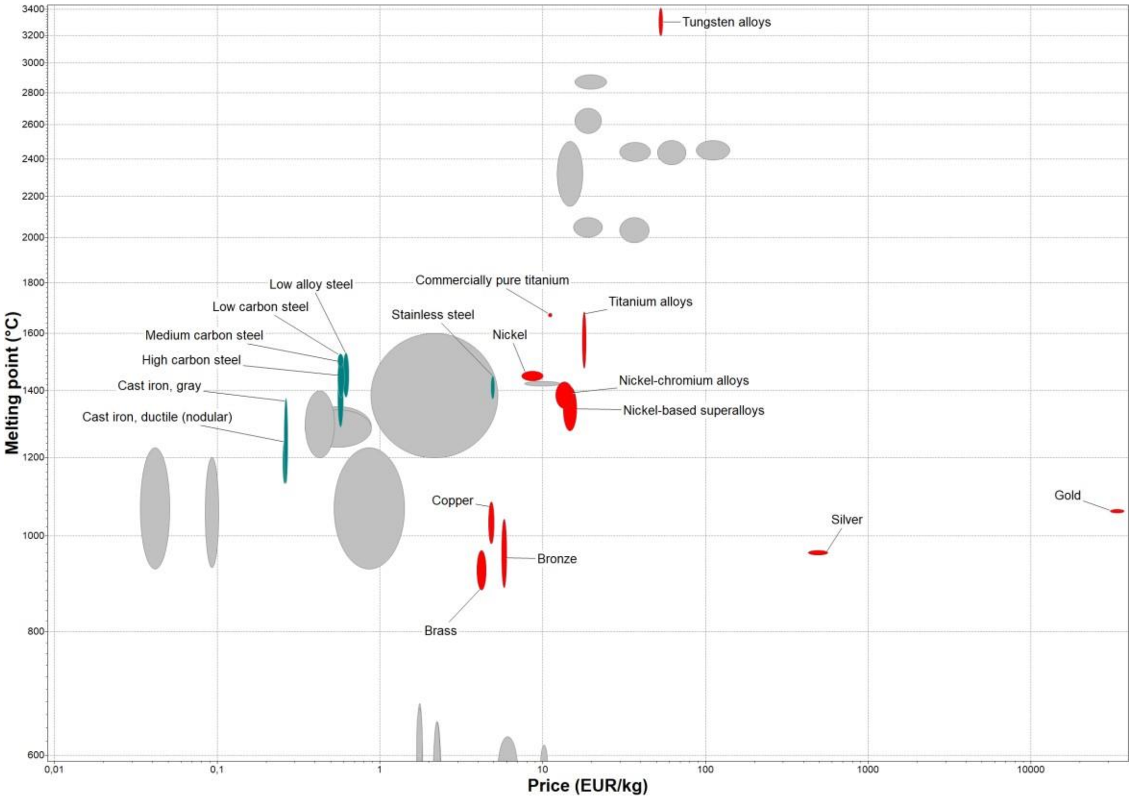

***Figure 11**. CES EduPack 2018: Relating metal alloys' Melting point with Price.*

To perform this technique, it was first needed to create prototypes, which in this case implied clay modelling the wanted shapes for the final products. Simple volumes resembling the silhouette of a fish scale were sculpted. After this stage, a mould was produced. The prototypes were uniformly distributed inside a proper container (Figure

12) with the dimensions of the mould to be made. To produce it, a balanced ratio of ceramic plaster and silica was added to warm water, preventing mould cracking when subjected to high temperatures. To produce this mould, ceramic plaster (1/3) and silica (1/3) were first mixed together, and then gradually sivted into a water container (1/3). This mixture was then cautiously sivted (preventing lump formation) and homogeneously poured over the previously modelled pieces (Figures 13 to 15). The blend is left to solidify: once it has dried out, clay elements were removed, leaving their negative forms in the ceramic plaster mould (Figure 16).

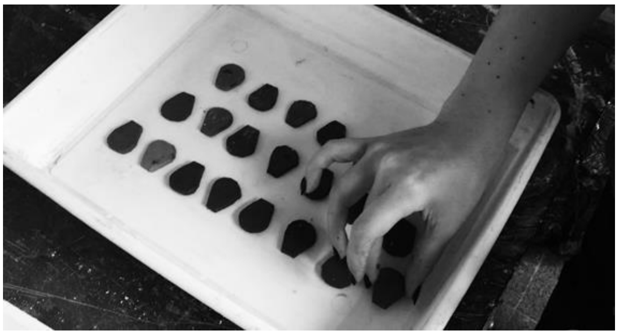

Figure 12. *Prototypes being put in a box-like container.*

Figure 13. *Sivting ceramic plaster and silica into water.*

Figure 14. *Pouring the blend over the modelled pieces.*

Figure 15. *The mixture is cautiously stirred and left to solidify.*

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Figure 16*. Clay remnants removal.*

The mould was again left to dry: that process can be natural, taking several days, or rushed through the usage of a kiln at approximately 200 ºC for four to six hours, depending on the size of the mould. Prototypes can be made using several materials, but in this case discarded float glass pieces were chosen: these were cut to fill the negative shapes in the mould. Two glass plates an (approximately 2x2.5x0,5cm) are required for each hole (occupying each empty space) to provide the wanted *sandwich* structure. The angular faces of cut-glass pieces should be softened. In this case a grinding wheel with an electroplated diamond disk was used (140 and 270grit), against which the glass was pressed to obtain the desired shape. There is no need for the pieces to be polished at this stage, as it is going to be exposed to high temperatures, slightly softening their edges.

Pieces were cleaned with alcohol before being put into place, to avoid any remaining impurities. A glass layer should be placed in each empty space; on top of that the previously washed scales and brass wires are put into place, followed by the second piece of glass, as shown in Figure 17. The mould is carefully positioned in the kiln which ideally will reach a maximum temperature of 710 °C.

Figure 17*. Glass and brass elements placed over mould concavities.*

Knowing that glass has unique characteristics in its transformation, further research on glass melting temperatures followed this phase. Used temperatures and glass stages were defined taking Bullseye Glass Company's articles, namely Technotes 4: Heat & Glass (2009) as a starting point and adapting its content to the pieces to be produced. Pieces are first exposed to an initial temperature of 540 °C. Glass pieces can shatter if heated too quickly or unevenly. This temperature will be reached within no more than two hours, as each individual glass piece is rather small. Temperatures from 620-680 °C precede the ascension to higher process temperatures, which prevents the creation of bubbles within gaps. The next stage is called rapid heat (538 ºC), before achieving process temperature. This transition should occur in one hour, approximately.

Usually, process temperature implies a range of 540-930 ºC for the glass to be formed according to tack fusing. These values can change through variables such as firing temperature and firing duration, depending on the

wanted results. In this case the pieces were soaked for 10 minutes at the previously referred process temperature. After that the kiln was programmed to cool until reaching a temperature of 480 ºC. Glass cooling should be taken cautiously to avoid any abrupt contractions: annealing - soaking (reaching 480 ºC) and cooling (from 480-270 ºC) occurred in a total of eight hours. Again, thermal shock should be avoided during cooling to room temperature (370°–30 °C). In this case kiln may cool at its own rate, with the door closed, until the interior reaches about 90
°C or lower. Then the door is opened, allowing the glass piece to cool down until it can be handled with bare hands. After the whole heating, curing and cooling cycle, lasting for one day, the pieces can finally be removed. Figures 18 and 19 show some of the first results.

Figure 18*. First pieces freshly removed from the kiln.*

Figure 19*. First obtained pieces after being cleaned with water.*

It should be borne in mind that this glass heating process involves a certain degree of unpredictability, which may take us to the next step - brass elements may still be subjected to a later finish. Depending on the results, if the piece doesn't yet have the wanted shape, an edge grind and polish can be made in order to shape the overall volume as intended, and also to remove sharp edges. This stage can be continued gradually, with an intermediate polish (using larger grain sandpapers) until it reaches the final polish (using very fine ones). However, it is ideal that the parts are as perfect as possible after the batch, so no finishing is required. Not only is this advantageous in what comes to sustainability, economy and time efficiency, but its aesthetically is significantly better, as glass appearance on polished surfaces will never be as clean and shiny as it is without polishing (after heating). Note that none of the pieces shown in the photographs throughout this document have been subjected to any roughing or polishing after fusion.

It was possible to realize that to arrive at different types of products and techniques starting from one single material.

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This process implies a longer period of production, although it does not require a great degree of specialization by those who manufacture the jewellery pieces, except for the use of a kiln. Although the material is exposed to high temperatures (reaching a maximum of 710° C) for a long period of time, the use of a smaller kiln may contribute to the minimization of energy expenditure. The scales are protected by layers of molten glass. Fish scales' perception is easily achieved through this technique, although some scales may scatter. The silvery hues seem to brighten up after glass fusion. There is a large unpredictability regarding glass behaviour when exposed to high temperatures, which may be considered a very positive factor if the changes are not significant (underlining the fact that each piece is unique), but it may on the contrary entail wastage of material and energy if changes impede its use as jewellery or even its aesthetic appearance.

Several prototypes were produced according to previously described techniques, both validating product reproducibility and allowing usability testing. This was followed by the production of photographs and video records which were later used to support a followed-up online survey, created given the need to evaluate the pieces regarding their perception and acceptance by the public in general. This survey also contemplates some questions regarding jewellery as a broader theme.

It is relevant to say that these pieces' target market was initially defined as middle-upper class women aged between 25 and 60 years; also considering an audience that not only appreciates fashion accessories, but also values sustainable production. This target market tends to grow according to the various polls that can be found online, forecasting increasing sales in jewellery and sustainable artefact production for the following years. In this case, the survey's sample is almost entirely made up entirely of Portuguese citizens, most of which resident in the Northern region of Portugal. All results were processed regardless of whether or not respondents belonged to the earlier defined target audience, given that the majority of respondents did not fit in this category, meaning lack of data to constitute a cohesive and reliable poll for statistics. Also, not only female answers were considered, given that, even though these artefacts may be thought for women, a products' buyers are not always their consumers.

After collecting all results it was found that the most relevant aspects driving the selection and purchase of a jewellery product (Figure 20) are the sale price, the aesthetics and the material that constitutes it, according to the order of importance attributed and the number of answers. Sustainability comes in fourth place in this chart, in comparison presenting a percentage consisting of less than half of that applied to the sale price (an aspect that was identified as the most relevant for the acquisition of a jewel).

Although the obtained results (considering sustainability) are not as positive as desired, the importance of the material constituting a jewel (80% of respondents considered that an important aspect) can be identified as a means of changing the way products are communicated and what they express; it can be significantly relevant for these products to come closer to the final consumers' expectations, yet bringing something new to their experiencing.

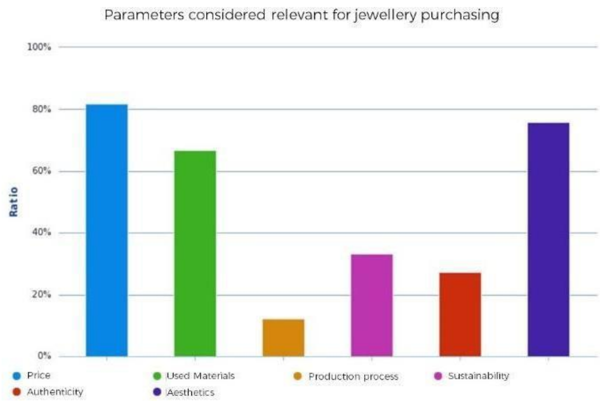

Figure 20. *Poll: parameters considered relevant for jewellery purchasing.*

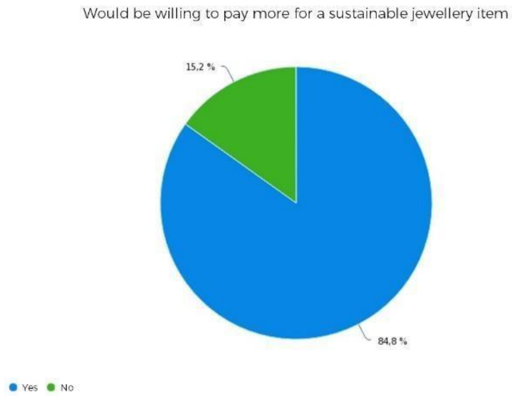

Figure 21. *Poll: willingness to pay more for a sustainable jewellery item.*

As seen in Figure 21, 84.8% of those responding to the survey would be willing to pay more for sustainable jewellery, which was considered a positive result. It will be of the utmost interest to continue disseminating this survey to get a greater number of responses, therefore obtaining a reliable representation of the existing total available market. As a future development, an exploratory research will take place focusing on these products' target audience and involving physical connection with the pieces, which will hopefully allow adjustments in order to improve their design.

3. Results and Discussion

The creation of sustainable pieces through alternative techniques to those existing in the market gave rise to the creation of two jewellery lines that, just as many kinds of ornaments do, praise for creativity as pieces of individual expression. It is believed that the designed jewels embody differentiating features as artefacts that are both humbly and proudly driven for the will to change the world we live in. This proposal comes to be disruptive in the sense that it takes upon an alternative to the mass production of jewels, in which modern processes increasingly deviate from qualified craftsmanship.

Reflecting on the obtained results, it is possible to verify that *Escama* (Figures 22 - 25) presents a set of earrings using pressed fish scales clusters with no added components, subsequently attached to brass. These reveal the strong fishing tradition that characterizes this town, through naturally appealing pieces that combine the simplicity and delicacy of overlapping fish scales' patterns - organic matter stands out for its bright hue and

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pearly glow.

Physical protection, as the material's primary function, is now transformed into symbolic protection, much like an amulet.

Figure 22*. Escama: round earring.*

Figure 23*. Escama: irregular earrings.*

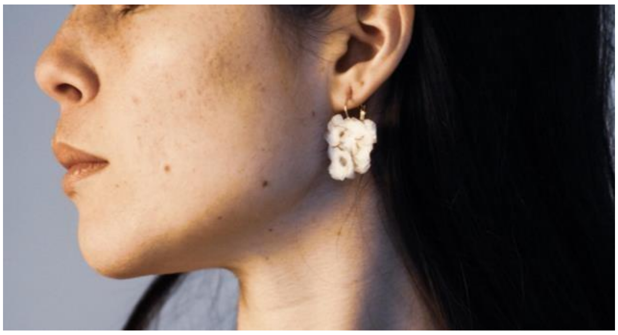

Figure 24*. Escama: irregular earring.*

Figure 25. *Escama: round earring.*

Maré shows a technique in which the fish scales are included between two glass plates, fused together along with brass strands. *Maré* jewels, represented in Figures 26 - 29, combine earrings and pendants made from discarded glass pieces exhibiting these fish scales as exquisite silvery elements. Each one of these pieces proposes a new life for this surplus material, enhancing its aesthetic qualities through the glass translucency and blue hues. They finally bring us Portuguese sea waters through the sophistication of a jewel.

Both lines (Figure 30) constitute good prospects for their application. Its greatest asset is definitively presenting an ethical alternative to mass jewellery, conveying a message of hope to those who contemplate, receive and use it.

Figure 26. *Maré: translucent navy-blue earring.*

Figure 27. *Maré: translucent navy-blue pendant.*

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Figure 28*. Maré: translucent white pendant.*

Figure 29*. Maré: translucent navy-blue earrings and pendant.*

***Figure 30**. Escama and Maré: Sea Jewellery exhibitors.*

4. Conclusions

With this exercise, gathering the Integrated Design Project methodology and Material Driven Design with the requirement to produce a functional prototype made the students pass through the different stages of product development by means of a Project Based Learning experience. In each step of the different phases, various methodologies were chosen to support product development, from laboratory tests to survey inquiries. Contacting with different areas was crucial for product development, and it was possible due the fact that the course is held by Faculty of Fine Arts and Faculty of Engineering. Dealing with real problems and trying to find different solutions to minimize them can be especially significant as a challenge.

It is necessary to refer Project Based Learning as a relevant methodology, providing students with a more complete experience. It is also worth mentioning the importance of design interdisciplinarity, in that sense of sharing and exchanging knowledge among different areas, alongside with holistic thinking.

Besides, the experimental phase focused on materials, guided by the Material Driven Design methodology (MDD), was fundamental for both lines, and the concepts were defined based on these experiences. It was very helpful as it contributed to reflecting and performing product design with an emphasis on material, so that the whole project proceeded from there. Its importance is unquestionable given how a material transforms both validation and valuation of a product, and how it can mediate meaningful experiences for its users. This exercise allows the opportunity to create artefacts with unusual concepts, evoking singularity as they seek to propose new alternatives to consumers. The reflection and experimentation from fish scales made it possible to act on two different paths, namely two different techniques (fish scales' thermal pressing and fused glass with fish scales, previously mentioned and explained). This proves the importance of experimental research in design, which can provide not just one solution for a certain problem or market need. Above all, this method allows the decoding of very pertinent questions regarding materials' technical, emotional and symbolic characteristics, which are projected in the conceived artefacts.

Speaking of Sea Jewellery, its production fits in a Slow Fashion model, creating well finished quality products -

- considering their longevity. Thus, in this case these pieces imply slower production processes, fair allocation of wages, lower CO_2 emissions and a commitment in the sense that each jewel should be composed mostly of discarded materials. Both lines reveal affordable manufacturing processes and can be carried out from a relatively low investment, which is inextricably linked to the fact that these are small-scaled products. It is intended to continue developing these pieces in order to improve their manufacturing details considering that they will be produced by vulnerable groups.

Although this products' development may be considered just a drop of hope in an ocean full of environmentally harmful methods, it aims to convey a strong, urgent message and contributes to ethically constructing a small part of the material universe that surrounds us.

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Circular and sustainable products. From theory into practice.

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Abstract

Circular economy is seen as an innovative path with the potential to achieve a more sustainable society. In this context, and, facing high pressure and motivation from governments, many research projects and initiatives are being developed all over the world. However, we still have a long road ahead in translating the theory and research outputs into practice. For example, in the recently launched report "The circularity Gap report" published by Circular economy in January 2019, our society is only 9% circular and the trend is still negative, the circularity gap is not closing and the upward trend in resource extraction and greenhouse gas emissions has continued in the past 12 months (Circle economy, 2019).

In the circular approach to product and service development, which entails fundamental changes in production and consumption systems, where it is necessary to go beyond resource efficiency and recycling (European Environment Agency, 2017), it's clear the importance of design as an integrating agent in the process. Design professionals, through a redesigned approach to the design practice, applying efficient tools and comprehensive life cycle methods, have the challenge and the potential to transform products, services, and business models.

The work presented in the current paper is part of a research project (Camocho, Ferreira, & Vicente, 2018) which aims to support the transition to circular and sustainable economy through design where the authors will explore the current practice, methods, tools and communication elements applied in the development and placement in the market of products claiming to be sustainable and/or circular. The pilot study presented in the paper aims to demonstrate and validate the procedure for the analysis of the process that underlays a representative sample of Portuguese products. The research aims to identify which are the real needs, drivers and barriers faced by designers and product developers in the circular design and development process. The results of the work will underpin a holistic approach, sparking critical thinking and supporting a more efficient design practice for a circular production and consumption.

Keywords: Design, Circular Economy, Life Cycle Assessment, Sustainable Products, Sustainability

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1. Introduction

The paper presents part of the research currently under development which aims to support the transition to a more sustainable and circular economy through design. The design practice has a crucial role in defining the characteristics of the products and services that fulfil the needs of society and most of their impacts on the life cycle are defined in the design and development phase through the designers and developer's choices.
In order to promote a sustainable and innovative design and its practice, it is important to understand how circular and sustainable products and services are developed and placed on the market, how they communicate to users their sustainability profile, how consumers understand the information available on the product; and which are the user perceptions about the circularity and sustainability profile of products and services.

The successful integration of circular economy in the design practice requires a new, or at least, an adapted set of principles, strategies, and methods (den Hollander, Bakker, & Hultink, 2017), in a holistic approach, considering all aspects of production to consumption, covering the entire life cycle of the product or service, is fundamental. However, despite the developments towards a circular economy, there is still a gap between what is developed at the research level and what is applied in practice by designers and companies, particularly in Portugal.

In this paper, the authors look to a specific part of the process related to the development of products in order to understand how designers and product developers translate the user and business needs in product design development. The identification of which methodologies and tools are applied in practice by designers and which are the needs, barriers and drivers in their practice in product/service development will promote the development of efficient resources to support the transition to a circular economy through design which is the goal of the research under development (Camocho, Vicente, Ferreira 2019a).

2. Background

The economic model in Europe is still linear which implies a huge pressure on the environment, human health and inefficient production and consumption of natural resources leading to an over-dependence of resources from outside Europe (European Environment Agency, 2017).

According to the recently released, Circularity Gap report, our world is only 9% circular and the trend is negative. The majority of materials used in our economy, which are not cycled, are not recovered and are either dispersed in the form of emissions or unrecoverable waste. (de Wit, Verstraeten-Jochemsen, Hoogzaad, & Kubbinga, 2019). The majority of products are still developed and placed in the market without a circularity perspective and at the end of their functional life, the majority are discarded and their value and materials are wasted, including the loss of critical raw materials (European Commission, 2015).
The linear economy, based on a take-make-use-waste system, has to change. The way resources are managed, how products are developed, produced and consumed and what happens after the functional life of products have to change in line with the boundaries of our planet (Ellen Macarthur Foundation) and the needs of society. The goal and challenges we face today are not to go backwards in the evolution of civilization but in redesigning our

society and the way of meeting our needs in an innovative, sustainable and circular way, attaining benefits for businesses, companies, and people such as

- innovative and efficient ways of production and consumption;
- protection for businesses against scarcity of resources and volatile prices;
- opportunities for jobs and social integration;
- optimization of waste management boosting recycling and reducing landfill;
- energy savings as fewer production processes require less energy;
- benefits for the environment in terms of climate and biodiversity, air, soil and water pollution (European Commission b).

The transition to a circular economy approach its seen as a potential way to alleviate the sustainability pressures and concerns and deliver economic, social and environmental benefits (European Environment Agency, 2017) and the design practice has a huge role in the process. The way we design, produce, use, distribute and discard products has strong impacts and most products developed and used today are not optimized, resulting in premature obsolescence. In this regard, designers have the responsibility of defining the product characteristics and its circularity potential: i.e., their reparability, durability, selection of materials, proportion of recycled and renewable materials, their suitability for refurbishment, remanufacture, etc (European Environment Agency, 2017; European Commission, 2019), and also by establishing the link to new business models and services which are required such as maintenance, repairing, reuse and reverse logistics and other services like sharing, leasing and renting services, as well as services that deliver performance (Bocken et al., 2016; BEUC, 2015), to increase the circularity potential of the proposed solutions.

Designers have the role of meet people's needs and develop technically and economically feasible products and services and in this new approach to improve the economy these professionals are challenged by new environmental, social and economic needs and must adopt a holistic approach to problem-solving (Bocken et al., 2016), supported by new knowledge and competences.

In order to promote a more effective design practice to circular product development, by supporting designers with improved tools and knowledge, the research under development is mapping the maturity of the design practice for circular economy in Portugal through the analysis the current procedures, drivers, needs, methods and tools adopted by the design professionals and companies. In the next section, the research method is explained.

3. Method

The activities under development are based on field research as a primary source of information aiming to identify and map the design practice for circular economy and sustainability. At this stage, the research team is identifying industrial products that are produced in Portugal and placed in the market (national or international) as being more sustainable. In this step, products that are placed in the market and communicated with allegations such as "circular products", "sustainable products", "eco products", "green products", etc, are being identified through literature, internet, magazines, social media, specialized shops (physical or online), exhibitions and fairs, by conducting workshops with relevant stakeholder and the creation and management of forums or discussion groups on social media platforms. The collection of products and all the relevant data is being gathered in a database of "sustainable" products that will be used to support the research.

In the second phase, the analysis of the tools and methods applied in the product development through direct contact with the designers and producers of a representative selection of products through questionnaires, phone and face-to-face interviews, workshops and other events will result in the understanding of how sustainable

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products are developed in Portugal and which tools and methods are applied in practice. This task will also allow the identification of the main drivers, challenges and the needs faced by practitioners.

Those professionals motivated to develop innovative and sustainable products are the ones that have been facing all the challenges and barriers required by enrolling in this development path, and by comparing what is available in terms of sustainability and circularity methods and tools with what is really applied in practice, the study aims to provide a clear idea on the extension of this gap and which are the real needs to support an effective and successful transition to more circular and sustainable economy**.**

The third phase will consist of measuring the effectiveness of the current practice trough a qualitative and/or quantitative evaluation of the sustainability profile of a group of identified products. The assessment will be based on the information available and will be performed by the application of life cycle assessment and circularity tools available. This analysis will be useful to perform an overview of the application of sustainability in the products available and how deep the concepts are rooted in the development process and communication of sustainability profile of products in Portugal.

Database of sustainable products in Portugal

Several platforms such as the ECO.NOMIA portal from the Portuguese Ministry of environment (www.eco.nomia.pt) and other commercial platforms such as the Planetiers (https://planetiers.com), Puro Verde (www.puroverde-ecostore.com) and many others have a collection of examples of sustainable products, however, these include examples from several origins, being difficult to understand which are developed in Portugal, and there is lack information on the criteria used as the basis to select them. Most of the examples rely on the allegations communicated by the producers, which in some cases can be misleading or even greenwashing (Camocho, Vicente, Ferreira 2019b).

The information and availability of Portuguese products are difficult to identify and even for the professional retailers of sustainable products, the access and availability is considered a problem. From a short consultation to these commercial stores, the main conclusions are that there are several products available on the global international market, but there is a lack of national products, and most of the products available with sustainability allegations do not have any form of validation or certification.

Within the research, several products are being collected in a database developed with a structure aiming to organize a wide sample and all relevant data. The initial version for research purpose was developed in excel, however, the goal in the future is to upgrade it into a user-friendly database that could be made available online to the public.

The structure was developed according to the needs of the research and it's based on the variables and information needed to support the planned research.

The structure of the database is divided into three main groups, "Background information", "Product and company information" and "Development process". In each group, several variables were identified as shown in table 1.

Table 1. *Variables in the sustainable products database.*

Background information	Product/company information	Development process
-Product name -Images and /or illustrations -Short description of the product -Company name -Source of information -The designer responsible for t development of the product - Sector - Contacts	-Allegations of sustainabili provided by the companies th place the products in the market - Certifications, labels, etc	-Criteria/type of strate implemented in the developme process - Methodology applied -Tools applied (related to the desi practice) -Barriers for development ar implementation -Drivers for development ar implementation - Suggestions

Questionnaires and guidelines for interviews with designers and professionals

As mentioned before, in the second phase of this process, the research aims to analyse which design and sustainability tools and methods were applied in product development by the designers and producers of a set of selected products to understand and map how sustainable products are developed in Portugal, which tools and methods are applied in practice, which are the main drivers, challenges and the needs faced by practitioners and other information which was considered relevant.

The questionnaires composed by a set of 20 questions were structured according to the needs of the research. Besides the general information of the company and the interviewee, the second section of the questionnaire aimed to collect data related to the sustainability profile and characteristics of the product, such as: the sustainability allegations used in the communication of the product; certification, which label does the product have and which is the opinion regarding certification and labelling schemes. Within section three, data related to the product development is collected. Which criteria and sustainability strategies were implemented, which methodology was applied, does the approach adopted have a life cycle perspective and which life cycle stages are considered, which design and sustainability tools does the professional knows and which of them are being applied in the process, which are the reasons for not applying tools, which are the main drivers for develop sustainable and circular products and which are the main barriers to integrate sustainability and circularity aspects in the development process.

In order to validate the structure of the questionnaire and the approach developed, a pre-test was performed with the designers and developers of three industrial companies with different characteristics from different sectors and maturity levels. In the next chapters, the authors present the preliminary results and conclusions of the test.

4. Results of the pilot test

In the preliminary test, the authors tested the procedure and structure with three distinct companies. In table 2, a short overview of the results is presented in order to demonstrate the adequacy and the potential data to be collected

Table 2. *Variables in the sustainable products database.*

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Designer/product developer	**Product developer A**	**Designer B**	**Designer C**
Type of products	Fashion products	Cork Products	Leather goods
Percentage of sustainab products in the company	100%	100% - All products ha sustainability consideratio in the development process	100%
The dimension of the compar	Small company	Large company	Small company
How the product is considere by the company	Eco-products Sustainab Circular	Circular products	Vegan Sustainable Ecological
Sustainability and circulari allegation used in tl communication of the produ	Sustainable productic Reduced environment impacts Environmental goals Use sustainable materials Reuse of produ components and material the end of life	Sustainable material 100 recyclable Use of recycled materia from the company and fro external sources Circular products	Vegan and sustainab design Handcraft process Vegetable and Nickel free Versatile and timeless
Is the product or the compar certified?	No	Yes (at company level and product level)	No
Certification schemes ar labels implemented	n.a	The company has sever certifications and labe according to the wide ran of products developed distinct sectors	n.a
Personal opinion abo certification and labels	Environmental certificatic is not required by the users	Important to communica the product performance	Important, but tl consumers are not aware
If available, could a specif label to demonstrate tl circularity of nation products is important?	Yes, very important	Yes, it's important for tl communication and to tl awareness of Portugue consumers	Yes, it could be interesting it has a good relationsh between the effort ar relevance of the label
Criteria and strategi implemented in tl development process	Use of sustainable material Vegan products Recovery products at the end of life f refurbishing or recycling	Use of sustainable material Reuse and recycling materials Material selection accordi to the function	Use of vegan materials A sustainable and manu process Durability and high quality
The methodology applied the design and process	Ad-hoc environment thinking in the process. No systematic approa used in the process	Product is developed wi sustainable principle however without systematic approach	The products are develope with sustainabili considerations following the criteria and objectives of tl company

Does the methodology used the company integrate a li cycle approach?	There are concerns about tl life cycle, but not in systematized way	Yes. But not in a ve systematic way	Not in a systematic way
Which phases of the Life cyc are considered	All (according to tl interviewee)	All (according to tl interviewee)	All (according to tl interviewee)
Tools to support the proce known by the deviser/produ developer	None	None	None
Does the company app sustainability tools in tl design process?	No	No	No
Identification of tools used the process	Not applicable	Not applicable	Not applicable
Reasons to not apply tools the development process	Lack of knowledge about tl availability and potential these tools	Lack of knowledge abo tools by the designers and t the company	Lack of knowledge abo tools
Main motivations to develo sustainable and circula products?	Environmental awarene Personal goals to develop sustainable produc Concern about anim welfare and biodiversi New lifestyles	The company is high engaged in the developme of sustainable products. The main material used is sustainable material wi high potential.	The company and tl designer is very engaged the development sustainable and vega products following the lon tradition of the company the development of leath products
Main barriers to tl integration of sustainabili and circularity aspects in tl development process?	Difficult collaboration wi suppliers In the subcontracting some parts and componen is difficult to enga suppliers Lack of trust in tl suppliers In some cases, tl recognition of sustainab materials is difficult or n perceived by the users Lac of consumers awareness Fashion is perceived main as handicraft and no industrial process Lack of long ter perspective by users	Cost. The material has higher cost and son consumers do not percei the benefits of the use of th material Lack of training of designe in sustainability too methodologies and process Data and releva information about tl sustainability and circulari profile of materials that ca be used in the design practi are not easily available designers	Awareness of the consum about the potential sustainability Higher cost of the materials Availability of raw materia with good properties Higher cost of the productio

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5. Conclusions

The research activities are being developed to understand how sustainable products are developed in Portugal and which are the main needs and barriers of the design professionals in adopting and implementing sustainability and circular economy measures in the design process. The research methodology foresees that this survey has a starting point in the identification and analysis of national products that are placed on the market as being sustainable and/or circular. From the products collected in a database created for the project, the team is analysing how companies are communicating the product profiles to consumers, how the information reaches the consumer, and how the products are developed in practice within the industry. Through direct contact with the professionals responsible for its development, it is intended to understand which are the real motivations and needs of the designers.

In the context of the analysis required, a questionnaire was developed as a guideline for the interviews and its structure reflects the data needed to understand how sustainable products are designed in Portugal. The majority of the questions are open questions, which usually promotes the discussion and exchange of ideas between the interviewer and the interviewee, which is a positive approach in this case because it not limits the perspective of the interviewees and allows a broader collection of useful data that need to be analysed and synthesized by the project team.

Based on pilot interviews carried out to test and validate the structure and the approach defined, and the examples and information included in the products database, a preliminary analysis can be performed. In this context, it is clear that all the professionals that are dealing in a daily basis with the development of sustainable and circular products are very much engaged and motivated to develop and place in the market innovative and efficient products that contribute for a reduction on the impact of the production, consumption and use of products. In most of the companies, when there is the goal of sustainability, the approach is extended to all products and activities and this is also reflected in the allegations that are used to promote the products and the companies. In general, the principles like use of recycled materials, reuse of products and materials, reduction of material and energy consumption, use of low impact materials and processes are the most common allegations, however, it was identified that, despite the fact that there are some life cycle aspects in the development process, the design practice and product development do not have a systematic life cycle approach. Which is also reflected in the absence of certified products in Portugal. Regarding certification, the general knowledge and perception about certifications and labels by the users are very low (Camocho 2019) and companies do not have in general the motivation to enrol in certification processes. The relation between the cost and the benefits of certification is very low and the majority of the companies tend to adopt self-declarations and allegations without any kind of verification and validation and, without any life cycle assessment and validation process.

Most products and services are placed in the market and promoted based on the assumptions of sustainability that result in some cases of the adoption of measures that have the potential to lead to sustainable or circular products, but, without a proper methodology, life cycle thinking and a verification procedure, these products and their allegations can be misleading for the consumer or even considered as greenwashing. A good example of this aspect is the generalized use of cork in Portugal. Cork is a very good and sustainable material but there is a general perception that all products made from cork are sustainable. Most of these products are placed in the market as sustainable products, however, in some cases that it's not true because there are other impacts related to other aspects of the products that are not accounted.

Within the design and development process, the integration of sustainability and circularity aspects is applied based on a non-systematized approach related with personal knowledge and motivation and in most of the cases, the design practice does not have the support of proper methodologies and tools that help the professionals in integration of sustainability and circularity principles and criteria in all stages of the life cycle. Currently, there are several tools available that can support the design process, however, the designers and the companies are not aware of their availability and the benefits of their application.

Despite the efforts and wide promotion of circular economy and sustainability, there are still several barriers in the transition to circular economy and sustainability; the design professionals, in general, still don't have enough competences, knowledge and skills to integrate these aspects in an efficient way; the engagement of stakeholders in the value chain is difficult; the costs linked to the production of these products can also act as a barrier and the consumer awareness, which is increasing, is still marginal and related usually to niche markets.

An important consideration that was verified in the research is that the designers and companies that are in the market with the goals of sustainability and circular economy are highly engaged in the process, and despite all the barriers faced in their daily activities, these professionals want to have a role in this transition in the society with a long term perspective.

Based on the research project and the activities under development, the authors supported by mapping the maturity of the design practice for circular economy and sustainability and through the analysis of the practical experiences, motivations, barriers and needs of the design professionals which are dealing with the challenges of the process, will develop an updated methodology, guidelines, tools and other resources to support the design process for the circular economy.

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Circular Economy in Fashion: 3 case studies in the Basque Country

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Abstract

Circular Economy has become one of the key paradigms in the process of sustainability development. It also has been seen as a solution to the challenge of resource depletion and waste and emissions generation that face companies and governments. The implementation of the principles of Circular Economy in companies has both drivers and barriers. Innovation has been perceived as an important aspect in the transition from a linear to a circular economy, and its absence or the lack of technology hinders the progress of a successful CE. In this paper, we explore this issue: Is sustainability as a core company value a driver for innovation? This study examines the role that innovation plays in companies that deploy a circular approach. First, we present ideas from recent academic literature to deepen our understanding of the relationship of these two concepts. Second, we focus our analysis on three case studies in SME fashion companies located in the Basque Country: one specialized in women's garments, SKFK; the second in outdoor wear, Ternua; and the third in clothing for children, Twin&Chic. These companies are currently implementing models of circular economy or have a sustainable attitude towards the management of the firm. These initiatives are related to very different aspects such as the way to operate (usage of renewable energy, recycled paper or biodegradable plastic, reusing the packing boxes, etc); or more disruptive innovations like a new business model or the development of a new fabric using recycled material and with high technical performance. The paper explores how this commitment influences the company's innovation project in each case. To conclude, we note the key driving role that sustainability plays in innovation, particularly through Research and Development projects carried out by these brands in partnership with other institutions: companies, universities or research centres, and with the support of local, regional, national or international institutions in order to accomplish them. Further, entrepreneurship appears motivated by the search for new methods or models to achieve efficiency in the value chain process or to fulfil customers' requirements. The three cases show that there is possible to be sustainable and to make profit. Moreover, sustainability can be a competitive advantage.

Keywords: Circular Economy, Innovation, Sustainable Fashion, Entrepreneurship

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1. Introduction

The increase in world population makes the current production and consumption system untenable in the long term. The limitations of resources and the damage done to the environment require politicians, manufacturers, and consumers to shift towards more sustainable behaviours in production and consumption.
The fashion industry is one of the most polluting economic sectors. To function responsibly, companies in this sector should begin adopting more sustainable actions in their operations. Big companies have started to take some actions, but these affect only a small proportion of their total production. Our study focuses on small and medium-size enterprises (SMEs), 99% of businesses in Europe, according to the European Commission (2019).

They provide two thirds of the total private sector employment, thus leading job generation. Furthermore, according to Eurostat, in the past five years they were responsible for 85% of all the new jobs created. SMEs can play a transformative role in achieving sustainability. Indeed, many are committed to it. We will discuss three of these companies in this paper and explore how this commitment influences the company's innovation project.

1.1 Circular economy

Circular Economy (CE) is a theoretical approach to production systems, which aims to respond to the sustainable challenges of population growth as well as social and economic development. The growth has led to, among other things, an increased demand for water, energy, and food. The current consumption patterns are not sustainable in the long term. Climate change, degradation of ecosystems, and the depletion of natural resources are environmental problems that illustrate the need to move from the current linear system (take-make-use-dispose) to a more sensible system that attends to the limits of our planet. CE emerges as the answer to these challenges because it dissociates growth in resource consumption from increasing prosperity.

Many scholars have argued in favour of CE. Pearce and Turner presented the idea in 1990, building on the concept introduced by the ecological economist Boulding (1966), who deployed the analogy of a circular system as a prerequisite for the maintenance of human life on earth. In 1987, the Brundtland Commission called for new strategies of production that would resolve the sustainability challenges of our planet: essentially, they sought to develop a model that would satisfy current needs without harming the requirements of future generations. McDonough and Braungart (2002) emphasize the importance of closing loops in a cradle-to-cradle, rather than cradle-to-grave, economy. Ideas from Industrial Ecology serve the context of circular economy in the analysis of industrial systems operations, from the Industrial Metabolism of Ayres and Simonis (1994) and optimization. Industrial symbiosis and system theory also support the theoretical frame of CE (Iung and Levrat, 2014)

CE emerges through three central actions, the so-called 3R principles: Reduction, Reuse, and Recycling. The Reduction principle aims to minimize the input of primary energy, raw materials, and waste through the improvement of efficiency in production and consumption processes (e.g. introducing better technologies, or more compact and lightweight products, simplified packaging, a "simpler lifestyle", etc.). The reduction of environmental impact is thus achieved in two ways: by using fewer resources per unit of value produced, and by replacing harmful substances in favour of less harmful ones per unit produced (Ghisellini, 2016). The Reuse principle states that "any operation by which products or components that are not waste are used again for the same purpose for which they were conceived", European Parliament (2008). This principle is compelling in terms of environmental impact because it requires less energy, fewer resources, and less labour compared with manufacturing from virgin materials, recycling, or disposal. It is highly useful for products such as clothes, books, furniture, glass, among others. The popularity of the reuse principle implies an increase in consumer demand for reused and remanufactured products. As a result, companies are motivated to design products for multiple cycles of use, take back the products at the completion of their life cycle, and promote the marketing of remanufactured products. Finally, the Recycle principle refers to "any operation by which waste materials are reprocessed into products materials or substances whether for the original or other purpose. It includes the reprocessing of organic material, but it does not include energy recovery and the reprocessing into materials that are to be used as fuels" (European Parliament, 2008). Circular economy is often erroneously identified with recycling. However, recycling is the least sustainable principle and should be considered only if reuse is not possible. Reduction and

reuse are more profitable and efficient in terms of environmental impact. In time, the 3R principles were extended to 6R: reuse, recycle, redesign, remanufacture, reduce, and recover (Williams et al. 2017). In general, these principles are implemented in five fields of action: take, transform, distribute, use, and recover materials and energy from used goods. Industrial symbiosis is a sixth field of action that focuses on the relation with other companies (Park et al. 2010).

The Ellen MacArthur Foundation actively promotes CE values. Among others, it presented the principle of reclassification of materials into "technical" and "biological nutrients". Technical materials such as metal and plastic are designed to be reused at the end of the life cycle. As biological nutrients are non-toxic, they can return to the biosphere or enter in a cascade of consecutive uses. The Foundation also fosters the idea of renewability which means using renewable energy as the main source for circular economy, thus reducing fossil energy dependence.

Circular economy has been implemented in different countries in recent decades. Germany pioneered the Waste Disposal Act in 1976, and Japan with the Law for Effective Utilization of Recyclables of 1991 (Ghisellini 2016). China implemented CE with the Circular Promotion Law in 2009 (Smol et al. 2017). Elements of CE were first regulated in the European Union in 2008 with the Directive 2008/98/EC on waste. But not until the "Europe 2020 Strategy for smart, sustainable and inclusive growth for 2014-20" did CE function with an action plan, waste resource goals, and a measure of success (European Commision, 2010). At a global level, in 2015, the United Nations proposed 17 Sustainable Development Goals (SDGs) to be achieved by 2030, a wide frame for the CE.

1.2 Fashion industry and sustainability

The fashion industry increasingly contributes to pollution because of heightened demand. Clothing production has doubled from 2000 to 2014. According to the McKinsey Report (Remy et al, 2016), during that period demand increased in part because garment prices decreased. Moreover, consumers keep clothes half as long as they used to, and the number of products they buy has increased 60%. The number of garments produced annually exceeded 100 billion for the first time in 2014. Fast-fashion has caused an explosion of consumption, leading to serious environmental impact. High water usage, pollution from chemical treatments used in dyeing and preparation processes, and the disposal of large amounts of unsold stock through incineration or landfill deposits are some of the adverse effects of the fashion industry.

Both big brands and SMEs are aware of these problems and are beginning to tackle them. In December 2018, 43 partners signed the Fashion Industry Charter for Climate Action, with the commitment to support the goals of the Paris Agreement 2015. They promised to reduce 30% the greenhouse gas emissions by 2030 and follow the

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movement towards circular business models among other requirements. By the end of July 2019, the number of participants reached 73, among signatories and supporting organizations. In March 2019, United Nations launched The Alliance for Sustainable Fashion to turn fashion into a driver of the implementation of the Sustainable Development Goals, reducing its negative and social impacts. The Alliance coordinates UN bodies working in fashion, fosters knowledge sharing, improves harmonization and synergies between existing initiatives, and works to achieve a unified UN voice addressing different stakeholders.

If we analyse the five fields of action of CE for the fashion industry, there are challenges in the selection of raw materials, in the manufacturing processes, in delivery and, when consumers purchase the garments, in their use,

care and disposal. Current technologies are incapable of transforming discarded clothes into new fabrics and markets can no longer absorb the products that would result from recycling processes. The aforementioned report states that nearly three-fifths of all clothing produced ends up in incinerators or landfills. Even Germany, which outperforms other countries in recycling, reuses half of the used clothing collected and recycle one-quarter. And what happens to the other quarter?

1.3. Innovation and circular economy

Innovation is crucial for the growth of companies, industries, and regions. According to the Oslo Manual (OECD and Eurostat, 2005) innovation involves the implementation of a new or significantly improved product (good or service), process, marketing method, organizational method in business practices, workplace organization, or external relations. Innovation makes companies more efficient and productive, solves technical problems, markets products more effectively, and develops new solutions for customers, among others.

For the purpose of this paper, we base our perspective on innovation on Ana de Jesus's notion of eco-innovation (2018), which she defines as "a new or improved socio-technical solution that preserved resources, mitigate environmental degradation and/or allow recovery of value from substances already in the economy".
Often, the inability to innovate becomes a barrier to CE. Preston (2012) points out the limited dissemination of innovation as a barrier of implementation of CE. Riztén et al. (2015) note the low technical skills of workers, as one of the six barriers for the development of CE in SMEs, the other barriers being: environmental culture, financial limitations, lack of legislation, information deficit, and administrative burdens.

Innovation is clearly needed to implement a circular economy, and its absence or the lack of technology impedes the progress of a successful CE. In this paper, we explore this issue: Is sustainability as a core company value a driver for innovation? To answer this question, we present the cases of three SME companies of the fashion industry located in the Basque Country.

2. Methods

We adopt an explorative case approach to study how a sustainable culture influences innovation behaviour in companies. Our multiple case method serves to provide answers to "How" and Why" questions (Rowley, 2002). To conduct the research, we selected three SMEs in the fashion sector located in the Basque Country: SKFK (established in 1997), Ternua (1994), and Twin&Chic (2017). We chose these companies because of two key characteristics: sustainability as a core value and innovative performance in the recent past.
Information from companies was collected between May and July 2019 using two sources:

a) In-depth semi-structured interviews with CEOs or senior managers of these companies.

b) Information available from websites, reports, and other publications (in accordance with the principle of triangulation).

3. Results and Discussion

In this section, we introduce each company and we present how they behave sustainably and within the five fields of action of the circular economy proposed by Park et al. (2010): Take, transform, distribute, use, and recover. We also explain the innovation performance in each case.

3.1 SKFK

SKFK started its activity in 1997 (as "Skunkfunk"), producing clothes for both men and women. It evolved over the last 20 years, and the company currently focuses on women's fashion with an urban and chic style, with a creative touch. The company changed its name to SKFK to reflect its new focus. It can be considered a slow-fashion company with a strong commitment to ethic fashion. The company headquarters is located in Lezama (Vizcaya). By the end of 2018, SKFK had 25 shops in Europe and North and South America. In addition, it has 600 other selling points in 38 countries. Its overall revenue for 2018 was 15 million euros and they employed 150 staff.

In the last few years, SKFK has become more and more committed to both social and environmental sustainability: the reduction of its carbon footprint, CO2 emissions, and ethical trade are critical values for the company. Therefore, the firm has gradually taken actions to reduce its environmental impact. SKFK products could be considered, to some extent, circular. Their design is timeless, elegant but free of the influences of changing fashion tendencies, so its garments can be used for a longer period.
SKFK has taken measures in the five phases of action in the circular economy:

Take: First, the company uses a percentage of ecological, reused and recycled fibres. They use organic cotton purchased from a cooperative of small farmers and other players on the supply chain in India, Chetna Coalition (Chetco), that works with 38,000 farmers. Brands purchase the cotton one year in advance, paying a fair price and a premium for local development, which is the core of Fair Trade. Its cotton is certified Fairtrade. Other fibres used are linen, hemp, and some artificial material like viscose and Lenzing® Lyocel, a durable fibre from sustainable eucalyptus forests. Recycled fibres are also used by the company: cotton and wool from diverse textile products and recycled polyester produced from waste, such as single use plastic bottles or Nylon from fishing nets.

Make: this firm has opted for a slow fashion production. That means that it takes 15 months since the design of a collection of garments until distribution in the shops for selling. They only produce two collections per year. They have adopted a Zero Waste design for some of its products in every collection. This design strategy aims to create garments without fabric leftovers; the idea is to make the best use of the length and width of the fabric. Another good practice of the company is that all the electric used in offices and shops are is provided by green sourcing Companies, Goiener Cooperative or EDF.

Distribute: the firm has significantly reduced the plastic in its packaging, utilizing only what is necessary to protect clothes during transport. Nevertheless, the plastic used is 90% biodegradable, made out raw vegetal materials. They use recycled carton boxes that can be reused several times. All the packaging is compostable. They also have had a zero air-transport policy for production, due to the carbon emissions. For long distances, they use sea freight

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and trucks for short distances. In the electronic commerce, they use a reusable and returnable packaging system aimed at reducing the waste of the massive consumption of single-use packaging.

Use: the company has introduced a business model innovation: clothes rental. They offer the customer the possibility to rent an outfit for a month, without having to buy it. This allows customers to use different and good quality garments for less money and reduce the number of items in one's wardrobe. The company is pioneering in this transition from paying for ownership to paying for use.

Another interesting initiative is the pilot project Klinica, a clothes repair service offered in their flagship store in Bilbao. The project aims to make garments last longer. Fashion designers, tailors, and innovators are involved in the project. In addition, they offer a personalized service to customers, a kind of laboratory where they test and develop solutions for textile and fashion problems. Further, they upcycle non-repairable garments in collaboration with other brands.

Recycle: the company deploys a high percentage of recycled fibres in their production process, such as polyester, Nylon or cotton. They also collect clothes in its shops for recycling. For this, they collaborate with Koopera, a non-profit group of cooperatives and social insertion companies which supports the job insertion of people in risk of social exclusion through projects that protect the environment or social innovation activities.

The company is seriously committed to the reduction of its environmental impact, fuelled by its CEO and transmitted as central to their company culture. SKFK continually innovates in the five fields of action: new fabrics in cooperation with their suppliers; innovation in energy supply, diverse compostable and recycled packaging; innovative business models (renting garments), and increasing the percentage of recycling, repairing, and reusing. The innovation develops in collaboration with other companies: Chetco, Goiener, UPS, Koopera, and several tailors and designers. So, SKFK also promotes good practice too in the sixth field of action: industrial symbiosis. The objective of these innovations is twofold: they look for improving the quality and the customer experience, and make the whole production process more sustainable.

3.2 Ternua

Ternua is a sportwear company, specialized in outdoor wear, that opened in 1994, with a commitment to sustainability and the environment. The company has its headquarters and a logistics platform in Arrasate, (Guipuzcoa), where it manages all the shipments through Europe. For the rest of continents, it is supported by two other platforms in Hong Kong and Puebla (Mexico).

Ternua distributes its products in a multi-brand channel with 1,200 sale-points, 500 of them abroad. The firm also has an online shop with growing activity. In 2018 its billing was 27 million euros and the number of employees was 175.

The company promotes an ambitious challenge: to offer a sustainable product with high technical performance. Since the beginning, the company has tested its new products with elite outdoor sports athletes: the alpine climber Alberto Iñurrategi; Juanito Oiarzabal, the first Spanish mountaineer (and 6th in the world) to climb all 14 eight-thousands; and Patxi Usobiaga, a multi medallist climbing champion, among others.

Their commitment with sustainability has led Ternua to innovate with the use of recycled material and the elimination of harmful substances in its production processes. In fact, the company leads the field in recycling. For instance, they were the first company that used recycled fluff from other industries (such as mattress manufactures) in its garments. 50% of its garments are made from recycled materials and they are also recyclable.

The recycled materials include train carpets, coffee grounds, fishing nets, plastic bottles and other garments already in disuse.
The firm developed the “Commitment Label” for more than 90% of its products. This label signals garments produced with recycled materials, organic cotton, biodegradable natural and Bluesign® certificated materials. The company began using organic cotton in its products in 2006 and, as of 2009, do not use any other type.
In 2009 they progressively began removing PFOA/PFOS and PFC, very toxic substances, from water repellent coatings, eliminating them completely from their products by 2018.

They have developed new fabrics: Dryshell, DryshellPorWool, Microshell, Shelltec, ShelltecActive, Windshell, Shellstretch, naturalshell and Thermalshell. Each of them has specific characteristics, consequence of the mix of natural and synthetic fibres in order to provide the adequate features to the final product.
They used biodegradable materials (plastic or recycled paper) for the packaging.

They are involved in Industrial Symbiosis projects upscaling and using waste from other industries in their products. We will show two examples:
REDCYCLE: is a project carried out in cooperation with local institutions, Basque associations of fishermen and Aquafil, a company expertise in recycling processes. The objective was the collection and recycling of discarded fishing nets to give them a new life by turning them into sustainable garments.

NUTCYCLE: A project that reuses agricultural waste (nutshell) and applies it to garments as a natural dye, to lessen the use of artificial dyes. The project is developed in collaboration with The Environment Department of the Gipuzkoa Provincial Council, the association of Cinder Houses of Guipuzcoa, and Archroma, a company expert in natural dyes. The nutshells come from the walnuts that are eaten as desserts in typical Basque cider houses.

The firm has a clear motivation for sustainability. The product, outdoor garments, is sought by people who connect with the idea of taking care of the planet; therefore, they value the sustainability actions carried out by the company. The company’s innovation projects generally seek two objectives: the improvement of the technical performance of the garments and the sustainability and circularity of the products.

3.3 Twin&Chic

Twin&Chic is a very young company located in San Sebastian. Its activity is the design and production of ethical and ecological children’s clothing. The idea for the company arose when Erika Gómez Villoslada, founder and designer of the brand, could not find garments made from sustainable materials and that took into account the sensitivity of babies’ skin, for her new-born twins. She discovered an unmet market niche and saw an opportunity in it. She started working on the idea and as a result, in 2017, she launched Twin&Chic.

The product is conceptually sustainable: garments for children made from high quality fabrics and a classic and elegant design. The fundamental idea is to make a product that lasts longer and can be reused by siblings, cousins, or friends. The circular principle of reuse is essential to the product design.

The company’s strong commitment to sustainability is based on three key points: caring for children's skin in contact with clothes, attending to the working conditions of the people involved in the production, and being mindful the environment.
The way of making clothes and doing business is summarize in the following hashtag used in the branding of the

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company: #FUTUREISFORCHILDREN. The meaning is more extensively explained below:

- Caring for their future: Respect and care for the environment to give our children the future they deserve. Because a cleaner, more sustainable and, above all, healthy planet is possible.
- Caring for children's health: Their sustainable fabric takes care of children's skin by not incorporating toxic components such as pesticides or dyes dangerous to their health. In Twin&Chic they want to reduce the alarming growth of children's allergies derived from the use of materials that are harmful to their health.
- Caring for the planet: All Twin&Chic garments are produced using sustainable materials and processes. Organic cotton or linen, their preferred fabrics, consume half as much water as conventional cotton and eliminates the use of synthetic fertilizers and pesticides.
- Caring for people: At Twin&Chic they work with local suppliers that bring their years of knowledge to all their designs, recovering traditional sewing techniques such as smock.

Twin&Chic uses 100% natural cotton and linen, from organic agriculture, without mixtures. In addition, all the fabrics used in its products have the GOTS certificates to guarantee traceability of the fabric and respect for the environment and labour rights. The company values the traceability of the fabrics they use, as well as the quality of the raw materials. The materials do not have toxic ingredients or dyes that are harmful to children's skin. The leftovers from the manufacturing processes are collected to reuse.

The company has taken measures in the five fields of action of the circular economy (Parker, 2010). Take: use organic fabrics with the GOTS certification.

Transform: the pieces of clothes left over in their production processes are collected to give them other usages. In addition, the company produces all its products in Spain.

Distribute: the packaging is made of very good quality carton, for reuse. It does not add dyes or any kind of glue.

Use: the products of Twin&Chic are conceptually sustainable because they are designed to last longer and be reused.

The founder of the company believes that being sustainable makes the Twin&Chic clothes more attractive to the consumer. For that reason, the company provides this information in the product labels. That is, sustainability is a competitive advantage for the company. In fact, the demand is growing in the national and international markets. Proof of this is that despite of its short life, the company has already customers in Italy and Japan.

Twin&Chic's commitment to sustainability has pushed the entrepreneurship process and also helped the company compete in the market at national and international levels.

From the point of view of innovation, the company is involved in two research projects. The first one is related to the recovering of growing and processing of linen in the Basque Country; other local and regional companies, institutions, and research centres participate in this project. The second one is carried out in collaboration with a university. Its aim is developing a standard of quality in fabrics related to children's health.

This small and relatively new company could not afford to develop any independent research but participating in a network with similar sustainability interests allows it to lead the drive towards sustainable fashion.

We have shown three companies in which sustainability is a key value. We have interviewed the founding CEO in two of them, and we have spoken with one of the top managers of the third one. In all three cases, we are talking to people with a strong conviction and commitment to sustainability transmitted to the entire company, that influences the way they operate and plan the future.

4. Conclusions

The three companies discussed in this article not only have sustainability as a core value but also as a real commitment with practical consequences. Therefore, projects continually arise that help make the process or the product more sustainable and to reduce the environmental impact. These projects are related to very different aspects such as the way to operate (usage of renewable energy, recycled paper or biodegradable plastic, reusing the packing boxes, etc); or more critical innovations like a new business model or the development of a new fabric using recycled material and with high technical performance.

Very often, SMEs do not have the resources necessary to carry out innovations than require R&D on their own. As such, they often join with other companies, universities or research centres and count on the support of local, regional, national or international institutions in order to accomplish their goals. They are involved in these projects not only motivated by the expectations of achieving benefits, but at the same level, by the hope of improving the sustainability of the company and reducing its environmental impact.

Product sustainability is important for many consumers. The recent increases of sales of the products of these companies prove that statement. Similarly, the sustainability of the company, which produces and/or sells the product, increasingly matters to the customer. Consequently, product sustainability is becoming a competitive advantage. Consumers can obtain information about companies and products without difficulty; therefore, to be credible, sustainability should not be a merely reputational aspect.

The three cases illustrated in this work show that it is possible to be sustainable and to make a profit. It is possible that companies that do not understand this fact will lose customers in the near future. On the contrary, companies that assume sustainability as a value have a competitive advantage.

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Food and Waste

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Investigating the role of residual food waste recycling in closing the loop: Case study from the 2018 Commonwealth Games, Australia

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Abstract
Every year in Australia, household, commercial and industry sectors generate more than 5 million tonnes of food waste, with the majority of it ending up in landfills that are costly to run and diminishing in availability. Furthermore, landfilled food waste in Australia is estimated to result in nearly 8 million tonnes of carbon dioxide equivalent over the year it takes to decompose. These figures highlight the significant need to address the greenhouse gas contribution of food waste. There are substantial precedents globally of the resource recovery industry reducing the volumes of food waste ending up in landfill, effectively 'closing the loop' on the flow of nutrients from – and back to – the soil. There are also significant precedents of doing so in ways that contribute to the 'circular economy', where selling products containing composted food waste reduces the environmental footprint of cities, creates local jobs and fosters new and diversified industries to collect, transfer, process waste. In achieving the target of reducing food waste by 40 per cent by 2020 in Australia, the industry would also be addressing the United Nations Sustainable Development Goal 12 'Responsible Consumption and Production'. Reflecting on this context and opportunity for improvement, this paper presents the findings of a research project to assess food waste recycling on the north-east coast of Australia in South East Queensland, specifically through evaluating a major residue food waste recycling initiative during the 2018 Commonwealth Games (Gold Coast). More than 6,500 participants from 71 Commonwealth Games Associations participated in the event requiring 18,000 meals per day. With more than 1.2 million visitors and global broadcasting, such events raise awareness about environmental stewardship and local actions for global impact. This research used stakeholder theory to provide a theoretical lens to the study. The research methods comprised contextual literature review, stakeholder interviews including event attendees, and field observations. Data was gathered over 6 weeks including pre and post stages of the games. Questions related to desire, challenges and opportunities in engaging with food waste recycling programs were included. The authors conclude the success of the 2018 Commonwealth games event in 'walking the talk' of a clean game, achieving a clean food waste stream and providing an excellent opportunity to demonstrate the potential for recycling food waste into a high-quality saleable product. Furthermore, innovative and streamlined practices for managing the transfer and processing of food waste demonstrated proof of concept for South East Queensland. This research provides evidence for key stakeholders such as local councils, food suppliers/vendors and the local community, to promote the value of creating high-quality food-waste streams for collection and processing, linking large-scale food waste recycling to job creation and environmental benefit. The authors propose a stakeholder engagement model arising from the research, that can immediately assist stakeholders in engaging in food waste recycling practices. The paper is valuable as a globally relevant, local example of sporting entities, commercial food enterprises, the waste industry and government all working together to realise substantial environmental, economic and social outcomes.

Keywords: Residual Food Waste, Recycling, Stakeholders, Circular Economy, Responsible Consumption

1. Introduction

Nearly 50 per cent of Australia's household waste consists of organic waste, highlighting significant opportunities for households and businesses in Southeast Queensland (SEQ) to divert waste away from landfills. The Queensland Waste Avoidance and Resource Productivity Strategy (2017) envisages Queensland becoming a national leader in adopting innovative resource recovery approaches, through diverting waste from landfill to manage all materials as valuable resources. To work towards this aspiration of national waste and resource leadership, it is critical to strategically involve key stakeholders such as local community, councils and businesses, academics informed by the waste and resource management hierarchy shown in Figure 1.

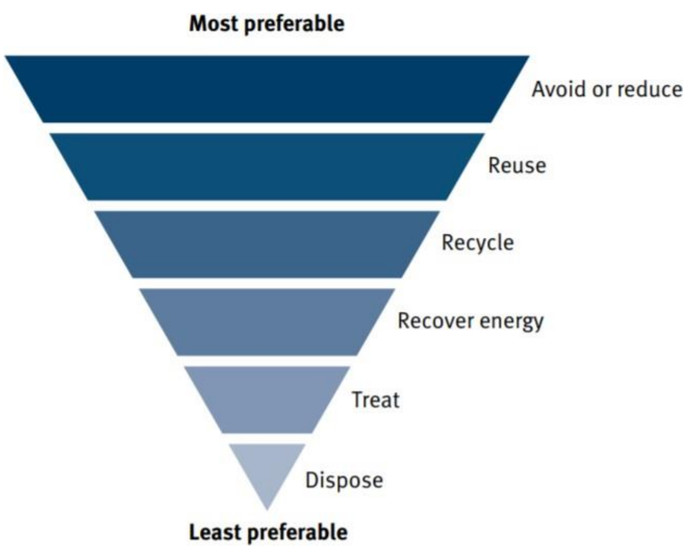

***Figure 1**: Waste Hierarchy (Queensland Waste Avoidance and Resource Productivity Strategy, 2017)*

Figure 1 describes the order of preference for options — from avoiding, to reusing, recovering, treating and disposing of waste. In the following sections, we build on this understanding to discuss the context for waste and resource leadership potential in SEQ, learning from the Commonwealth Games efforts within the context of our current and emergent urban waste challenges and opportunities. The unit of analysis in this exploratory study is the waste recycling company which will be referred as Firm A throughout this paper. Firm A was engaged with food waste recycling trials with the Gold Coat City Council and was then recommended to the Gold Coast 2018 Commonwealth Games Corporation (GOLDOC) to become involved with the Games' food waste management. It is critical to note that the food waste recycling initiative focusses on the residue food waste after implementing the reduce and reuse steps of the waste hierarchy.

The 2018 Commonwealth Games (XXI Commonwealth Games) were held on the Gold Coast, Queensland, Australia in April 2018. This major sporting event had over 6,500 participants from 71 Commonwealth Games Associations. This event required 18,000 meals per day and involved 790 staff members in the Commonwealth Games Village. The back of the house waste generated from the game's venues were separately collected three times a day and then transported to local waste management venues, where the contracted collection trucks were

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permitted to access. In achieving the target of reducing food waste by 40 per cent by 2020 in Australia, the industry would also be addressing the United Nations Sustainable Development Goal 12 'Responsible Consumption and Production'. Reflecting on this context and opportunity for improvement, this paper presents the findings of a research project to assess food waste recycling on the north-east coast of Australia in South East Queensland, specifically through evaluating a major residue food waste recycling initiative during the 2018 Commonwealth Games (Gold Coast).

Appropriate waste management practices are identified as a vital prerequisite for sustainable development (Shekdar, 2009). Reflecting on historical urban contexts, waste management was generally targeted on eliminating hazarders substances that poses a risk to humans (Wilson et al., 2015). However with that type of unsustainable management approach, social and financial implications became a major challenge for many communities (Effie Papargyropoulou, Lozano, Steinberger, Wright, & bin Ujang, 2014). This requires a major shift in the waste paradigm to more systematic and holistic management of waste acknowledging the higher order impacts. Within this context the concepts/ methods and mechanisms such as waste hierarchy, the '3Rs' (Reduce, Re-use, Recycle), extended producer responsibility, polluter pays principle (Oldenziel & Weber, 2013; Effrosyni Papargyropoulou, 2016; Effie Papargyropoulou et al., 2014), life cycle assessment and Sustainable Consumption and Production (SCP) (Roy et al., 2009) emerged to promote effective and sustainable ways of waste/ resource management (Effrosyni Papargyropoulou, 2016; Prior, Giurco, Mudd, Mason, & Behrisch, 2012).

Sustainable resource management is based on the premise that 'waste' can be a 'resource' (Bringezu & Bleischwitz, 2017). Material can only be a waste if it is at the wrong place at the wrong time. There are other associated benefits such as reduce Greenhouse Gas (GHG) emissions linked to climate change and will have positive economic and social impacts (Barrett and Scott, 2012; Defra, 2011). In the growing waste management field, a waste stream receiving growing attention is food waste. There are increasing calls for businesses to engage in food waste recycling due to large proportions of food waste generated and its negative environmental, social and economic impacts (Van Ewijk & Stegemann, 2016). Firm A's Food waste journey aims to implement efficient waste management and recovery processes to effectively transform 'wrong time and place food waste', into a compelling commercial 'right time and place composting resource'.

This project involved evaluating the stakeholder engagement in Firm A's food waste recycling initiative for the Commonwealth Games and enquiring into ways of better engaging with key stakeholders to determine the importance of food waste recycling. This included documenting the characteristics of waste received and the value-adding process, visualising Firm A's interactions with stakeholders including the public and suppliers in South East Queensland, and mapping and sharing the findings with key stakeholders.

This research enquires into two research questions as follows: 1) Who are the key stakeholders influencing the food waste recycling initiative? and 2) How can stakeholders influence recycling practices? Building on this overview of food waste challenge, and relevant waste and sustainability concepts, in the following section presents key literature and the theoretical framework. Section 3 presents the research approach adopted in this study. Section 4 provides the findings of the exploratory study followed up by a discussion in section 6. Within the discussion authors analyse the key findings through the theoretical lenses of 'Stakeholder theory' and 'Whole of society approach' and establish a stakeholder engagement model. Finally, the conclusions of this research are presented in Section 6, along with the implications of the study for food waste composting.

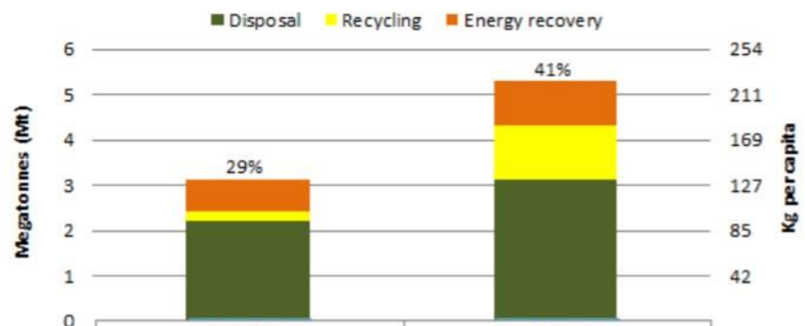
2. Literature Review

This literature review is twofold. The first section presents key literature findings on food waste related to the Australian context. The subsequent section describes Stakeholder theory which is used as a lens to analyse the research findings.

2.1. Food waste in Australia

Every year in Australia, household, commercial and industry sectors generate more than 5 million tonnes of food waste, with the majority of it ending up in landfills that are costly to run and diminishing in availability. Most of this food waste contains spoiled fruits and vegetables, food products that have passed their expiry date and leftover food. Wasted food should not be just viewed as waste of money but it is critical to understand that it is a waste of the resources used throughout the food life cycle including the phases of growing, harvesting, transporting, processing, storing and distributing. Therefore, it is critical to develop efficient recycling methods to recover the food waste (Pickin & Randell, 2017)

Figure 2 shows '*food waste generation and its fate'* by source sector in Australia. Most of the food waste is produced in the domestic sector which results about 3.1 mega tonnes (Mt). About 6 per cent (0.2 Mt) of collected MSW food waste was recycled, mainly through composting. A proportion of 23 per cent (0.7 Mt) was used for energy recovery (Pickin & Randell, 2017).



	MSW food	All food
Generation (kg/cap)	133	224
Generation (Mt)	3.1	5.3
En recovery (Mt)	0.7	1.0
Recycling (Mt)	0.2	1.2
Disposal (Mt)	2.2	3.1

The stated percentages are the resource recovery rates = (energy recovery + recycling) / generation.

Non-hazardous and hazardous organic waste generation and fate, Australia 2014-15 (Pickin & Randell, 2017)

This highlights a significant opportunity to increase resource recovery and landfill diversion in Queensland. It is now the responsibility of local councils, businesses and community to engage in initiatives for better management of food and organic waste. According to the survey data 373 reporting entities including key stakeholders such as

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local governments; private landfill operators; recyclers; organic processors; waste transporters and transfer station operators; incinerator operators; and industrial and mining operators, it was evident that there 1.4 million tonnes of waste was collected and converted into products such as potting mixes and mulches through organic processes (Figure 3).

To further advance these practices innovation and collaboration will be key to develop new solutions that will produce better outcomes for our environment, economy and society. Closing the loop has emerged as an approach to lower the waste going into landfills and retain resources in the system for a longer period. The 2016-2017 organic processing survey presents the commercial and industry waste materials collected and recovered.

Figure 3*: Waste percentages from 2016-2017 (Recycling and Waste Strategy Report, 2017)*

The typical waste hierarchy refers to the 3Rs; reduce, reuse and recycle. However, the reality is that most people are reluctant to reduce their use of things (Pickin & Randell, 2017). Reuse is still relatively gradually improving through change of consumer behaviour however still there is a significant proportion of food waste generated annually. Recycling rates have improved over time but still leaves considerable quantities to be disposed of in landfill. In Queensland $678 worth of food per household per year is disposed (Recycling and Waste in Queensland, 2017). After reducing the quantity of food wasted, and maximizing recovery and distribution of edible food, the subsequent step in the food cycle is composting. The compost can then be used to improve soil health and in turn grow more food to put back into the food cycle (Figure 4). To achieve best outcomes in this closed loop of food production, recovery and recycling, the residue food waste generated needs to be contaminants (i.e.: polythene, plastic and glass) free (Levis, Barlaz, Themelis, & Ulloa, 2010).

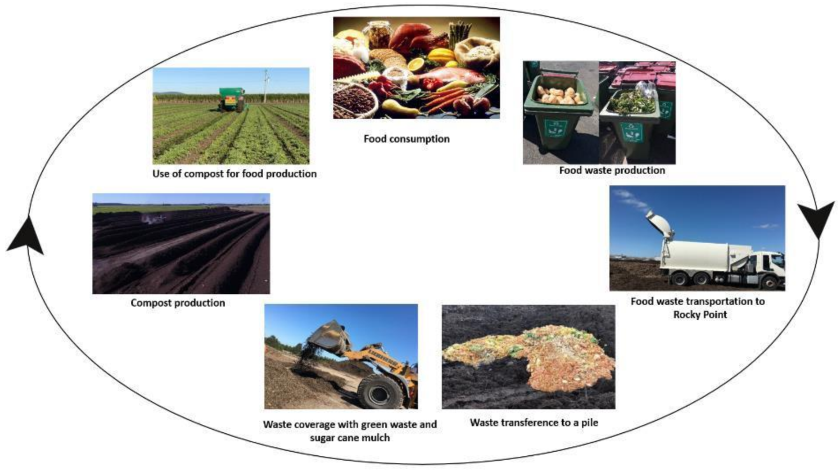

Figure 4: *An illustration of the food waste recovery process, from consumption through to composting for food production*

Composting is a way of decomposing organic matter that is easily able to be taken up by plants as nutrients. The process involves green and brown organic material (Griffin, Sobal, & Lyson, 2009). The green material is high in nitrogen and the brown material is high in carbon. Usually in a mixture in equal parts of carbon and nitrogen, the organic material decomposes within a period of 6-8 weeks (Körner & Stegmann, 1997). This sustainable method is the culmination of the source's lifecycle providing nutrients and promoting soil health and in turn grow more food. Closing the loop concept suggests the everything as a reduce and to seeks to retain the the waste in the system for a longer period of time (Drechsel, Cofie, & Danso, 2010). In Australia this concept has been recognised as a targeted mechanism to shift from the linear to a circular economic system (Figure 5).

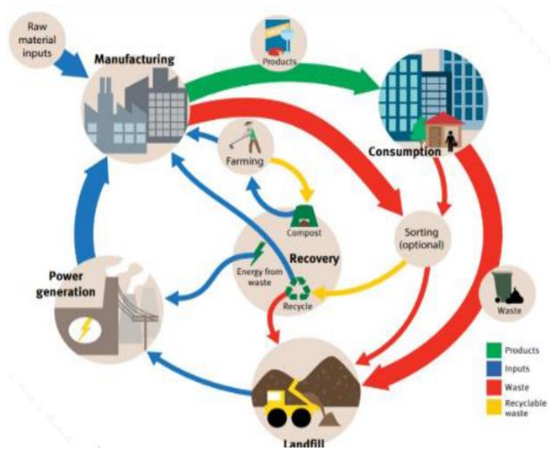

Figure 5: *The cycle/economy of waste (Queensland Waste Avoidance and Resource Productivity Strategy, 2017)*

2.2. Stakeholder theory and whole of society approach

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Stakeholder theory provides the foundation for identifying stakeholders from inside and outside a company to explain the types of influences various stakeholders exert over the company's sustainability initiatives. These stakeholders are categories as primary stakeholders and secondary stakeholders' practices (Freeman, Harrison, Wicks, Parmar, & De Colle, 2010; Freeman, Martin, & Parmar, 2007; Phillips, 2003). The primary stakeholders are "*one without whose continuing participation the corporation cannot survive as a going concern'* (Clarkson, 1995 p. 106). This group includes parties such as shareholders, employees, suppliers, customers, and financiers. These secondary stakeholders are "*those who influence or are influenced and affected by, the corporations but they are not engaged in transactions with the corporation and are not essential for its survival"* (Clarkson, 1995 p. 107). This group consists of entities such as media, special interest groups, government, and consumer advocate groups (Clarkson, 1995). Figure 6 provide a neat representation of the types of stakeholders interacting with the firm (Freeman et al., 2007) .

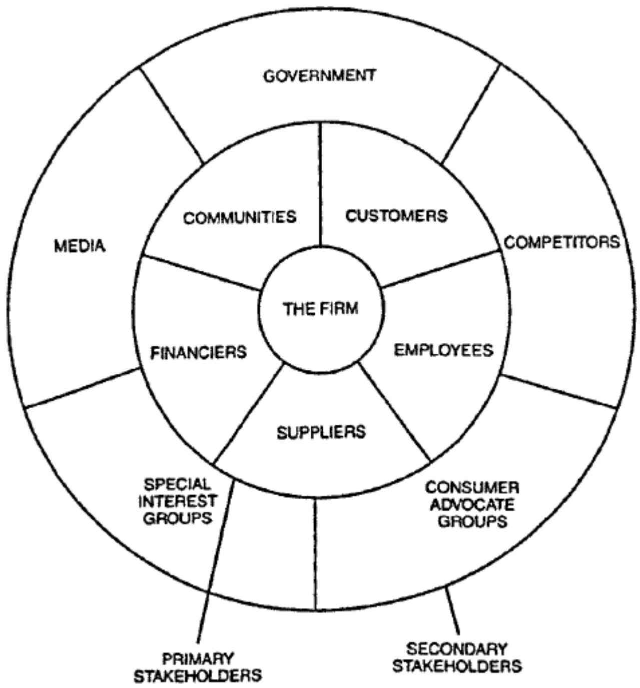

Figure 6: *Types of stakeholders (Freeman et al. (2007))*

Three branches such as descriptive (*how an organisation behaves*), normative (*how an organisation should behave*) and instrumental (*how behaviour affects performance*) are being described in the stakeholder theory (Donaldson & Preston, 1995; Zakaria, 2011). Within this context stakeholder theory is used to explains a companies' "*characteristics, including its nature, the way managers view issues such as stakeholder engagement, and the perception of managers and executives of the interest of stakeholders"* (Zakaria, 2011, p. 22). The instrumental view evaluates "*organisations dealing with stakeholders' interests in order to maximize their performance"* (Zakaria, 2011, p. 22). The normative base of stakeholder theory *suggests that managers should reflect on the interest of those who have stakes in the organisation"* (Zakaria, 2011, p. 22). Within this branch,

there is an argument that stakeholders' views should be considered because their interests have intrinsic value. Therefore, the company should take into account all stakeholders who have a moral stake in its actions/practices, although they may seem to lack influence (Donaldson & Preston, 1995; Zakaria, 2011).

The whole of society approach describes the importance of partnerships and stakeholder engagement in order to remain competitive in the market. Many companies acknowledge the value of key partners such as professional bodes, educational bodies, events, festivals, media, NGO's, community advocates and other business as demonstrated in Figure 7 (Hargroves & Smith, 2005). The authors have situated their partnerships analysis within these types of stakeholders to ensure a broad range of multi stakeholder engagement.

Figure 7*: Whole of Society Diagram (Hargroves and Smith (2005))*

Within this context the interview findings will be analysed using the stakeholder theory and whole of society approach as the theoretical foundation.

3. Methods

This section describes the research approach adopted to learn and evaluate Firm A's residual food waste recycling journey. The research approach included a review of key documents, interviews with stakeholders, consultation with local community members and field observations.

Relevant literature on food waste recycling in South East Queensland and closing the loop were reviewed to set the context for this research project. Other data including waste volumes, laboratory reports on product characteristics, Australian Standards for composting and mulch manufacturing, to triangulate interview data. The Commonwealth Games Village was visited to observe the point of waste generation, methods of waste separation. The Firm A's composting facility was also visited to observe the composting process of food waste. The processes were photographed to provide photographic evidence and to triangulate the interview data in accordance with research methodologies detailed by (Ray & Smith, 2012). Food waste recycling at the Commonwealth Games required the involvement of several key stakeholders from industry, local council and the event organiser.

Interviews were undertaken (ensuring anonymity of each participant) to explore stakeholder perspectives on food waste recycling, in accordance with university human research ethics approval. Potential participants were invited to participate in semi-structured interviews through a method of snow-ball sampling, whereby interviewees were invited to nominate other potential stakeholders. Invited participants included management and operations

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personnel with experience, from industry, Council and Commonwealth Games. Interviews were conducted in person on a date and time of participant's choice and convenience. The semi-structured interview questions were developed based on the findings of the contextual literature review, and participants were provided with a participant information sheet. Interviews were digitally recorded using a smart phone and then transcribed for data analysis (Bazeley & Jackson, 2013; Caldera, Desha, & Dawes, 2018). Through an iterative coding process, the emergent themes were identified. Within the coding process initially the in-vivo codes were developed labelling the data through a short word or phrase. Then these codes were categorised into higher-order axial codes to deduce the interactions. Finally, key emergent themes were used to create the selective codes which demonstrated relationships to all categories (Glaser & Strauss, 2009; Savin-Baden & Major, 2010).

4. Findings

4.1 Contractor Overview 'Firm A'

In this section we summarise the contractor's waste management practices, using quotes from interviewees, and a map of Firm A's interactions with stakeholders including GOLDOC and Council. Firm A view waste as an opportunity to convert this material into 'right-time-right-place' commercially compelling products. The company played a critical role in aerobically composting the food waste generated during the Commonwealth Games, modelling unique practices in creating value from waste.

4.1.1 Composting achievements

Overall there 98.32 tonnes of food waste were received by Firm A. Using figures based on previous trials at Firm A, the conversation of food waste is estimated to be in the order of 100 tonnes of food waste producing 1200 m3 of composted product.

The Production manager of Firm A established their vision for waste management as "*For us to take the organics from landfill – which increases their capacity and longevity – and return the finished compost to the soil was, apart from many other reasons, environmentally the right thing to do".*

Building on precedents in urban waste recycling, the food waste recycling process comprised three key steps:

- ***Windrow establishment*:** Each load of food waste was transported from Commonwealth Games venues to the Firm A facility, where it was registered for weight and time of delivery. Waste was then tipped into a stockpile, where it was mixed with green waste (sugarcane mulch) at a ratio of 6:1 (green waste to food waste) into windrows, to improve conditions for aerobic decomposition (Figure 8).

- ***Windrow management*:** Microorganisms in the sugarcane mulch facilitated the decomposition of the food waste and helped to generate and maintain the optimum level of temperature. Safety measures were

  taken to cover the food completely, protecting it from potential scavenging animals including foxes and rodents.
- ***Windrow monitoring:*** Regular monitoring of the composting windrows included sampling for different parameters such as pH, electrical conductivity, nitrogen and carbon level and ensured those products adhere to the finished product adhered to the Australian standards of AS4454-2012 composting and mulch manufacturing. Compost screening: After 12-16 weeks of monitoring, watering and weekly aeration (turning), the compost was screened

into different sizes according to the end-use.

Figure 8: a) *An example of food waste received by Firm A, and b) an onsite excavator covering food waste with green waste*

Stakeholders play a major role within this residue food waste recycling journey, "*there is a critical need to engage key stakeholders such as local councils, food suppliers, transport companies s and the local community to make this closing-the-loop initiative a success"* (Production Manager, Firm A).

4.1.2 Challenges faced during the food waste journey

As a trial before the Commonwealth Games, the City Council collected food waste from Gold Coast hotels such as Hilton and Sheraton hotels to ensure the processes are effective and produces compost which adheres to the Australian Standards. However, it was notes that the hotel food waste had different characteristics compared to the GOLDOC food waste. The hotel food waste largely contained sea food such as prawns, oyster and lobsters. Firm A management was careful about the level of proteins released from this food waste as it adds into the leachate.

Figure 9: *Contaminated waste*

The main challenge faced by Firm A during their food waste journey revolved around waste contamination. Waste loads received that included polythene and plastics (Figure 9) were not able to be recycled and were instead sent to landfill.

Another challenge identified from reviewing document registers and databases recording collection during the Games, was periodic lack of communication by the waste transportation company, resulting in several unstructured schedules of drop-off with associated down-time and human resources. According to the records, there were two

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truckloads rejected from Firm A as the collection route included general waste bins from Commonwealth Games venues. Approximately two tonnes (2% of total waste received) of truck loads were diverted due to this mix up of waste.

During this process Firm A acknowledged the importance of their interactions with primary stakeholders comparing the primary stakeholders such as GOLDOC and local council however notwithstanding their secondary stakeholders such as local community. Interview with the local community/event attendee also emphasized the importance of contamination free waste and it was suggested that more regulations are required on plastic usage. For example, "*we need mandatory laws on no plastic bags".* Next section will elaborate more on GOLDOC's role in the Commonwealth Games' food waste recycling initiative.

4.2 Managemen Overview 'Gold Coast 2018 Commonwealth Games Corporation (GOLDOC)'

This section evaluates the way managers viewed sustainability, and how the sustainable waste management agenda was taken forward, drawing on interview data.

4.2.1 Managing a complex organisational structure

The GOLDOC waste managers had a priority aim to sustainably manage the influx of waste that was produced during the games. In accordance with the organisation's Materials and Packing Policy, other priorities included using sustainably sourced material for packaging and making more productive use of food waste through composting. 'Sustainable operations' was the preferred approach for continuous improvement and many incremental steps were taken for significant sustainable outcomes. This included GOLDOC carefully selecting suppliers and local waste managing companies to recover the waste as much as possible. These objectives aligned well with Firm A's organizational objective of diverting waste away from landfill.

"*Sending waste into landfills imposes a threat to the environment. These wastes can have potential impacts on increasing greenhouse gas emissions. We want to recover the food waste and return it to the soil as compost*" (Manager Cleaning and Waste, GOLDOC).

Interviews with GOLDOC staff highlighted the importance of selecting the appropriate suppliers for the waste management, emphasizing that collaborative effort is key, with suppliers, contractors, workforce and spectators needing to each responsibly manage waste.

"*Certainly, we went through the procurement process to get our best contractor through that, value for money, local business and good outcomes*" (Manager Cleaning and Waste, GOLDOC).

"*In my role one of the biggest responsibilities was to manage the residual volumes and wastage, having an avenue to get rid of it. And it was critical to make sure those wastes were not going to landfil*l" (National Resource Operations Manager, in charge of the Commonwealth Games village cleaning and waste)

"*Sustainability is all about continuous improvement. Some people just don't know where to start with their sustainability journey. Incremental steps do add up and amount to bigger outcomes*" (Manager Cleaning and Waste, GOLDOC).

Interviewees highlighted the importance of awareness and education on waste management among the larger number of staff members engaged in processes within the Commonwealth Village. "*Pitches and training sessions were used to educate volunteers, workforce and contractors. Different level of training was provided before the games and on the ground re-iterating about reducing contamination levels*" (Manager Cleaning and Waste, GOLDOC).

The GOLDOC contracted workforce was trained for deliberate handling of waste separation and storage. They had three key training sessions offsite before commencing their first shift. Once arriving onsite, they undertook two more training sessions. The training included waste recycling as one of the important elements.

4.2.2 Logistics of managing multiple waste streams

GOLDOC's approach to recycling and waste management was based on the waste and recovery hierarchy, adapting the waste hierarchy as a 'resource recovery hierarchy' to encourage its workforce to think differently about the contents being handled. GOLDOC also had a major focus on the packaging policy, minimising packaging to avoid unnecessary packaging costs, demand for raw materials and carbon emissions. All packaging in-venue followed the sustainable sourcing code and the materials and packaging policy.

Within this categorisation, GOLDOC managed waste during the Games using 'front of house' and 'back of house' waste streams, using 120 litre (L) bins as they were easier for staff to handle. Front of house consisted of recycling and landfill, while back of house waste streams comprised liquid waste, food waste, recyclables, landfill and cutlery (Figure 10). General waste and organic bins were treated as general waste, recyclables were sent to recyclers, and soft plastics cardboards were all separated onsite.

The GOLDOC food supply team implemented specific efficiency measures to supply food on time while maintaining a high level of quality through cleanliness and hygiene, in accordance with GOLDOC internal standards. The village catered 18,000 meals per day to 6,500 athletes and other participants, including four meals: breakfast, lunch, supper and dinner. This included seven different cuisines and number of chefs to cook meals appropriate for multiple cultures. The food suppliers had about 20 minutes' change-over time in between meals to provide food. The interviewees noted the momentum created by international frameworks and experiences from previous large sports events (including international mulit-sports event experiences in Glasgow and Sydney) to prompt this level of waste consideration at the 2018 Commonwealth Games.

Before the GOLDOC food waste recycling initiative Firm A and Gold Coast City council did some recycling trials with food waste collected from two local major hotels on the Gold Coast.

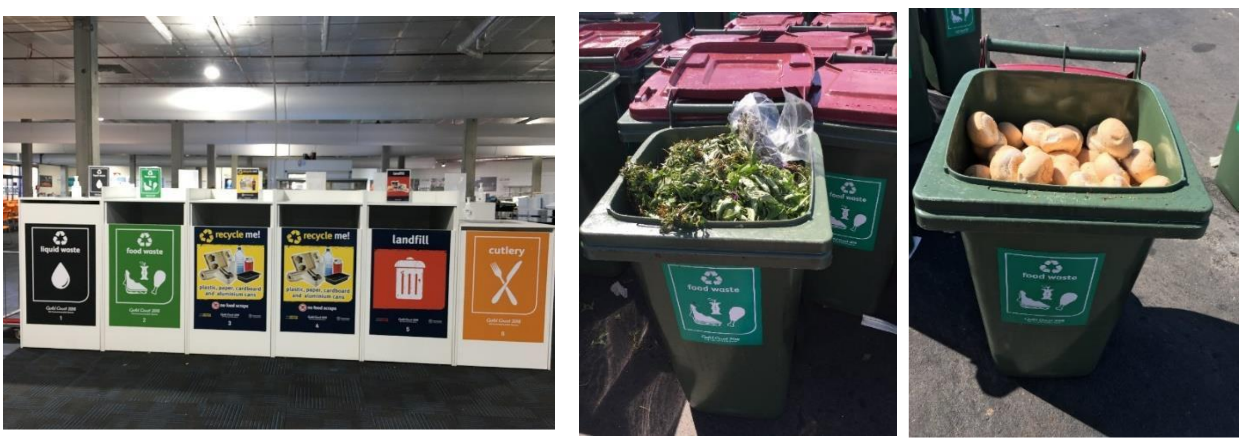

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Figure 10: *Waste segregation and food waste bins in Commonwealth Games Village*

Local community/ event audience were also encouraged to segregate their waste during in the game's venues. It was evident that they acknowledge that local councils, local business and academic institutions should participate more in advocating the food waste recycling agenda. For example*, "Council and Universities and local farmers can establish a project to show what food waste recycling could do for our region. Produce more jobs, preserve our soils, increase profitability in farming".* Furthermore, it was stated that more awareness campaigns especially in schools would enable positive consumer behaviour changes. For example, one local community member stated, "*perhaps drive this into primary schools so young children can get on board as they get older and carry it with them and pass it onto to the next generation and the next generation".*

4.3 Characteristics of waste received

A large volume of food was served during the Games which included 280 menu items on an 8-day rotation across four meals a day, resulting in about 18,000 meals per day. As shown in Figure 11 the highest volumes of waste were received during the games. This was further established by the information retrieved during the interview with the food suppliers at the Commonwealth Games village.

Interviewees noted the challenges of dealing with the volume of food waste as it was quite confronting for some employees to see the scale of the food being wasted. "*So, the hardest point is educating staff who have never seen that volume of food before in production. When you are standing at a clearing point, scraping food, tray after tray of what appears as consumable products is probably the most challenging part*" (National Resource Operations Manager, in charge of the Commonwealth Games village cleaning and waste). To overcome this challenge constant communication and education of staff was critical to get clear messaging about the importance of consistency in quality food waste for composting. Firm A received nearly 100 tonnes of residual food waste over 6 weeks including the time before for the games, during the games and after the games. The waste volumes received throughout this time is shown in Figure 11.

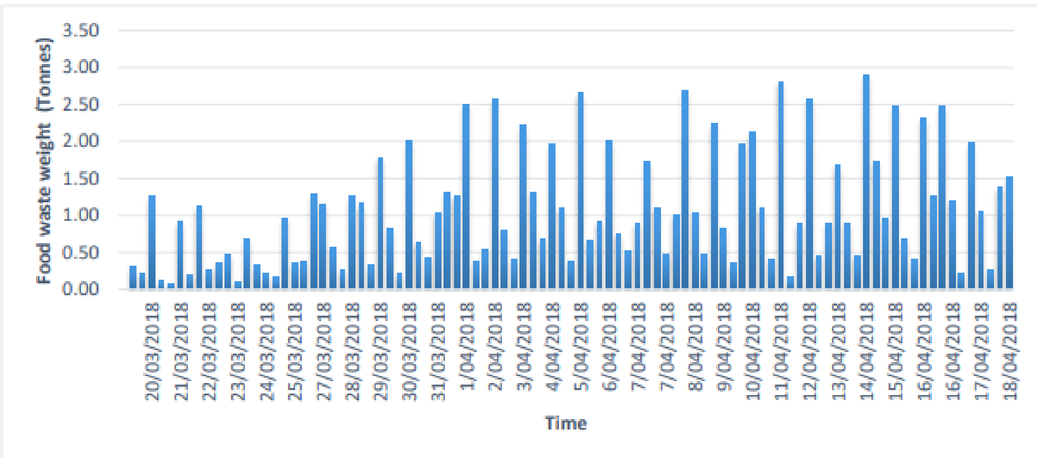

Figure 11: *Waste volumes received over the time*

5. Discussion

This section analyses the interview findings using the stakeholder theory and the whole of society approach to advance residual food waste recycling initiatives, towards creating a reliable food waste supply for industry growth in food composting. The whole of approach was used to ensure that the study has captured all potential types partners/ stakeholder and the stakeholder theory was used to then categorise the stakeholder and delve deep into their practice. As per the definition of the stakeholder theory there are two types of stakeholders such as primary and secondary stakeholders. Table 1 summarises the

Table 1: Identified types of stakeholders influencing Firm's sustainable food waste recycling agenda

Stakeholders	**Description**	**Examples**	**Associated stages of engagement**
Primary stakeholders	Officers and members within the Fi A who should be consulted for a decision related food waste recycli strategies	Operations manager Planning officer Business Development manager GOLDOC Waste transportation company	Consulting, involving Partnering
Secondary stakeholders	Individuals and organizations w influence or are influenced by Firm but they are not engaged in transactions	General public Academics Professional community Authorities	Informing, Consulting

Three aspects of the stakeholder theory of normative, instrumental and descriptive were used as key elements in analysing the findings of this research. According to the descriptive nature Firm A has the objective of maximising their profits while realising their sustainability objectives. As per the stakeholders interest the

normative way of behaving would largely focus on, responsible production, stakeholder engagements and social acceptance. Finally, the instrumental context is the how their behaviours affects performance which is clearly demonstrated through their business processes, partnerships with the local councils, local farmers and academic institutions.

Figure 12 presents a conceptual framework for stakeholder engagements, aligning interest to advance to food waste recycling initiative. The primary stakeholders have the key interest of producing compost products according to the Australian standard and be as efficient as possible in the operational performance. Food suppliers' interest are in efficient planning to reduce food waste and increase aware on clean food waste collection. The Gold Coast 2018 Commonwealth Games Corporation (GOLDOC) aimed to take appropriate measures to sustainable management the food waste, and carefully select supplies and waste management company's who are committed for sustainability.

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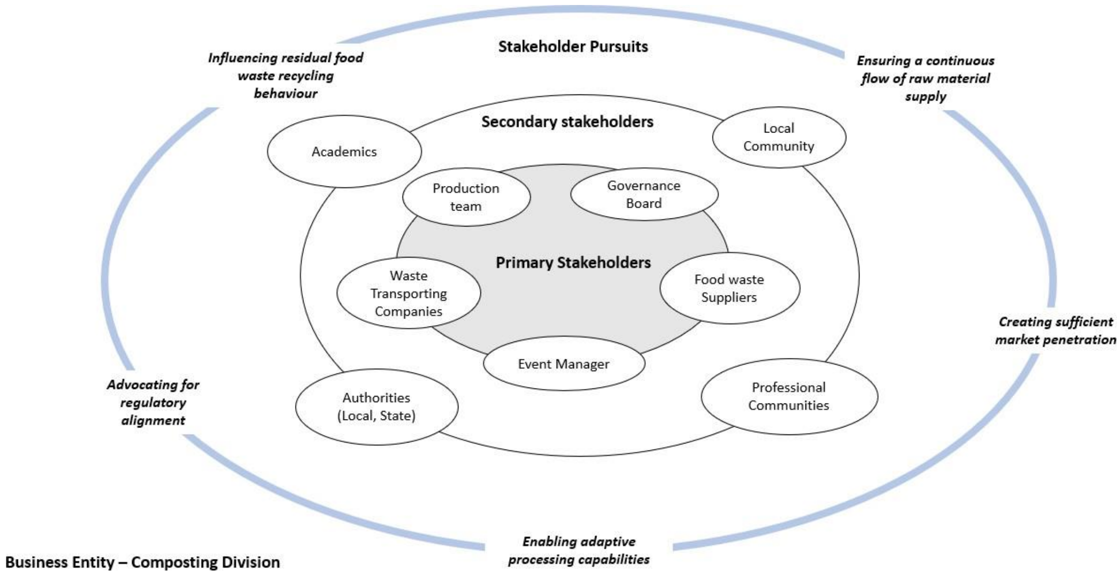

Figure 12: *Emergent stakeholder engagement model: Using Stakeholder Theory to advance residual food waste recycling initiatives, towards creating a reliable food waste supply for industry growth in food composting*

The local council, one of the secondary stakeholders highlighted their interest to develop simple and practical strategies to increase consumer awareness on food waste reduction and reducing contamination in food waste collection. They are also keen to introduce commercial level food waste collection services to divert the tonnes of food waste from landfills. The local community is interested in reducing waste in their daily consumption and use measures such as household composting to recycle the food waste and close the loop. Within this context the mutually sustainability interest could be realised if these stakeholders can collectively work towards advancing residue food waste recycling initiatives to close the loop. These interest of key primary (food suppliers, waste transposing companies, event manager/GOLDOC, Firm A production team and governance board) and secondary stakeholders (local community, professional community, authorities and academics) can be supported through the five stakeholder pursuits of influencing residual food waste recycling behaviour, creating sufficient market penetration, enabling adaptive processing capabilities, advocating for regulatory alignment and ensuring a continuous flow of raw material supply as demonstrated by the outer circle in Figure 12.

Table 2 presents the actions and the supporting tools/ mechanisms proposed for effective implementation of these initiatives. From the results and interviews, it is concluded that the Queensland government and relevant departments/bureaus have a significant opportunity to promote food waste recycling at household and business levels and bring in necessary regulatory support. There is a significant direct and indirect cost involved with food that is wasted. The direct costs only accounts for lost opportunities for more productive spending by households. It does not include spending by businesses, energy costs, costs of lost labour and materials, or the costs associated with other liabilities and risks. Therefore, it is important to educate the local community and businesses about the hidden cost of waste. It was evident from the interviews with stakeholders that they are aware of the existing food waste issue. They highlighted that food waste recycling could lead to creating more jobs, improving soil health and increasing smart farming opportunities. From this appreciation, the Table 2 also provide a suite of recommendations for stakeholders to advance residual food waste recycling initiatives, towards creating a reliable food waste supply for industry growth in food composting.

***Table 2**: Stakeholder pursuits to advance residual food waste recycling initiatives, towards creating a reliable food waste supply for industry growth in food composting*

Stakeholder pursuits	Key tools/ mechanisms	Key recommendations elicited from the stakeholder interview
Influencing residual food waste recycling behaviour	Quality assurance Quality control	Mainstreaming the concept of food waste recycling through large super-market chains while educating consumers about composting options Developing user-friendly apps which indicate reduced prices so that the consumers are notified about the discounted prices Improving school curriculums to provide practical and immersive experiences in food waste composting
Creating sufficient market penetration	Behavioural prompts Percentage growth analytics (product/ process)	Engaging with community to encourage positive consumer behaviour through nudge techniques Establishing effective communication between suppliers, retailers and customers Collaborating with the local council and engaging in further food waste trials
Enabling adaptive processing capabilities	Lean and green thinking Future flexible design and procurement	Implementing lean strategies for transporting materials and products to and from site Ensuring all materials, tools and machinery are placed in a system-optimised order and reviewed periodically Tracking and embracing advantageous technologies, e.g. through procurement, leasing, and sharing
Advocating for regulatory alignment	Professional association membership Australian Standards (quality/ bio security)	Prioritising responsible management of food waste in Queensland’s waste and recycling strategy Implementing practical strategies to collect organic waste from households and industry Conducting awareness campaigns to educate the consumers about the importance of reducing food waste contamination
Ensuring a continuous flow of raw material supply	Supply chain management Quality Assurance	Developing measures to ensure continuous procurement of residual food waste and green waste to produce compost and cater to the market demand Assessing the product quality to meet the Australian standards Assessing and addressing potential risk especially related to biosecurity hazards to ensure the produces could be delivered across states

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6.Conclusions

In this paper the authors establish a stakeholder engagement model (see Figure 12) to advance residual food waste recycling initiatives, towards a viable food composting industry. Five activities are synthesised as target stakeholder pursuits, relating to key internal and external stakeholders. Learning from enquiry into the relationships and practices of multiple stakeholders (including a sporting event entity, commercial food outlets, waste collection service providers and local and state government departments) the authors discuss significant opportunities for realising substantial environmental, economic and social outcomes. Furthermore, the authors conclude the significant capacity for further improvements in food waste management in South East Queensland, towards closing the loop on nutrient cycling and removing waste from landfill.

This research provides timely evidence for key stakeholders spanning local councils, food suppliers/vendors and the local community, to advocate for residual food waste composting. It also provides a narrative of the value of creating high-quality food-waste streams for collection and processing, demonstrating how large-scale food waste recycling can create jobs that have beneficial environmental consequences. The findings of this paper are valuable as a globally relevant, local example of a company transforming from conventional farming practices to a financially sound business model that includes residual food waste composting.

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Eating practices as part of daily routines: A practice-theoretical analytical framework

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Abstract

This paper explores the complex relations between practices and uses eating as an example to explore how it can be analysed as part of a broader network of food practices embedded in other daily routines. Using insights of social practice theory, this study proposes an analytical framework that includes different forms of connections between practices and how a change in one practice might reconfigure the whole network of food practices. Our framework contains elements, complexes, bundles, nexuses of practices and the context that shapes the network of practices. We show how integrative practices such as eating - encompassing different materials, meanings and competences - are directly connected in complexes according to criteria of sequentially and co-dependency to shopping, cooking and storing practices. That connection is different from bundles, referring to practices that compete for attention and priority across time and/or space with others e.g. eating shares/compete with work, leisure or childcare practices. In addition, we consider how practices are connected with other daily routines via

e.g. mobility practices, which form a nexus between different daily practices such as food shopping and bringing kids to school. Our framework proposes that the dynamic of the network of practices includes all those relations, which are shaped and influenced by a broader context, involving global trends, social norms, and cultural specificities. The analytical framework can be used for empirical analyses of existing networks of practices as well as of changes in social practices that have occurred in the past. It helps to understand the complexity of changing single food practices (as e.g. buying organic food, eating less or no meat) as being part of networks of practices. Since in the sustainability or health discourse change of food practices are often addressed in a rather simplified way, it aims at enhancing a comprehensive understanding of influencing factors and interactions. The paper presents insights on how changing elements of one practice might re-craft the whole network of directly and indirectly connected practices – an approach that can also be used in other fields beyond food studies.

Keywords: Food Practices, Social Practice Approach, Connections Between Practices, Network of Practices.

1. Introduction

Food and eating practices represent a subject that leads to a very instructive study, since preparation and consumption of food are intrinsically linked to many other central processes of social life (Warde, 1997). Eating habits and food consumption patterns, for example have impact on global food chains, affecting climate change, biodiversity and many others, representing one of the most critical domains from a sustainable perspective (Davies, et. al, 2014).

In this sense, eating is more than just digestive practices and changes in diets imply transformation of tastes and preferences (Paddock et al., 2017). However, researchers usually focus their analysis on the elements of a singular ''practice'' (Reckwitz, 2002, p. 249) and few studies have explored the interdependency of eating practices with other food related practices as well as how change in one practice might potentially impact the whole network of connected practices. Social practice theory (SPT) offers opportunities to reframe daily routines and gain a deeper understanding about the challenges of changing them, a claim that is prominent in the sustainability discourse.

From SPT, there is limited research exploring the relation of individual practices connected with or affected by others (Hiu, 2016; Shove and Walker, 2010; Warde, 2005). It is necessary to understand links and relationships that exist between both the components within a practice and between practices themselves (Hui, 2016), since changing how one practice is organized will have implications for all the others that are connected to it (Spurling et al., 2013:29).

Currently, there is some work of scholars on bundles (Jensen, 2017), complexes (Shove et al., 2012) or nexuses (Scollon, 2002); however the interconnection between them or the nature of the links and bonds involved are still underexplored both theoretically and empirically (Higginson et al., 2015; Shove et al., 2015). Higginson et al. (2015) are exploring the connection of practices in networks by applying a quantitative form of network theory to the field of energy demand.

Eating seems to be an interesting case, since it is a highly complex activity. Warde (2016) refers to at least four integrative practices - supply of food, cooking, organization of meal occasions and aesthetic judgments of taste - which are connected in food practices. The challenge lies in understanding the relationships that exist between these different practices. Warde (2016:158) points out that "recommending changes to only some parts of the practice of eating while ignoring the others is a likely source of failure". How and what people eat, is not solely based on individual choice, but depends on a series of interrelated social, political, cultural and economic factors, leading to more or less sustainable food consumption practices (Di Giulio and Fuchs, 2014). Eating practices have significant impacts on carbon emissions and climate change (Thøgersen, 2010) and therefore are often addressed in sustainability discourses, pointing out the necessity of change.

Since eating is not necessarily coordinated or regulated in the same manner as other practice-entities, a better understanding of eating as a social and complex practice is necessary (Warde, 2016; 2013). Diagramming eating routines could show not only how individual eating episodes are linked to each other (Jastran, et al.2009), but also how other practices are interconnected and have an influence on the performance of eating and food-related practices. These insights have gained importance regarding the necessity – and difficulties – of changing food practices from a sustainability point of view. In summary, there is a gap in the literature in operationalizing the connection of food related practices in complexes and to other daily routines being embedded in the

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surrounding societal context.

Addressing this gap, we defined the following research question for this study: How can the complex relations of food practices as being embedded in networks of daily routines be operationalized for analysis? To answer this question, we propose an analytical framework, which starts with the single practice (and its elements) and supports the step-by-step localization of this single practice in connections of different scope and quality ('zoom out'- perspective).

We will refer to the methods used in section 2, followed by the presentation of our conceptual ideas and the analytical framework (section 3) as well as referring to the use of the framework in empirical research (section 4). We end with some concluding remarks (section 5).

2. Methods

This paper has a theory-building nature, using existing literature from different strands based on social practices researchers mostly allied with Reckwitz (2002), Schatzki (1996), Warde (2013, 2016), Shove et al. (2012). It the family might be different from those with colleagues or friends, being connected to different meanings and material settings. Performances on a daily basis will be quite different from weekend practices and special events such as

suggests a framework on how to analyze eating practices as part of broader networks of practices. The methodological challenges in using practice theory have been recognized and addressed by many scholars (Halkier and Jensen 2011; Nicolini 2012).

In order to facilitate the analysis of the network of practices, we adopt a methodology based on Nicolini (2012; 2009). The author proposes a 'toolkit approach' based on the richness of plurality that characterizes the theory of practice. He suggests a general method for applying theory of practice, consisting of two basic movements: 'zoom in' the analysis (focusing on the achievements of the practice) and 'zooming out' (focusing on the relationships between practices in space and time), each with a specific focus (Nicolini, 2012: 213 -242). 'Zooming out' requires that practices are studied relationally within a broader framework. This means, among other things, comparing and contrasting different instances of a particular practice in different locations, following the links between practices and studying the effects of these associations.

The technique of 'zoom out' will be applied for the purpose of this article to propose a framework for the analysis of networks of food-related practices and their connections.

3. Results and Discussion

3 .1 Understanding Eating using a Social Practice Approach

The central unit of analysis of social practice theories are the practices rather than individuals or the social structures (Hargreaves, 2011). That approach has a considerable affinity with the sociological understandings of everyday life and emerges as a way to overcome substantive and explanatory deficiencies of cultural analysis (Warde, 2016). In addition, practice theory is not a unified and homogeneous theory (Schatzki, 2002), which allows the use of another term that would be more appropriate such as "practice-based perspective".

Eating, for example, can be understood and explored based on theories of practice (Schatzki et al., 2002), since the practice of eating itself is an extremely personal act and, at the same time, it is for most people a social act. In this context, it is important to mention some of the concepts proposed by Schatzki and Reckwitz, which serve as the basis for understanding eating as a social practice.

Schatzki (1996) differentiates dispersive and integrative practice. According to Schatzki (1996), dispersed practices are "widely dispersed among different sectors of social life" that are sets of doings and sayings mainly linked by a "knowing how to" perform, recognize and judge the practice (Schatzki, 1996: 91). Integrative practices, on the other hand, are sets of different activities grounded in some particular domains of social life such as cooking, teaching, transportation, etc (Schatzki, 1996, p. 98). For this study, we focus on integrative nature. Reckwitz and Schatzki differentiate practices as entities and performances (Schatzki, 1996; Reckwitz, 2002b). Practice-as-an-entity refers to socially shared taste and meanings, knowledge, and skill, material and infrastructure. and Practice-as-performance refers to the observable behaviour of individuals (Spurling et al., 2013). Using the eating practice as an example, the entity in question could be the practice of making a lunch - a practice, which as an entity, is carried out in many cultures including certain meanings, competences, and materials. However, the concrete performance of this practice can vary depending on the context where people eat and prepare their lunch (e.g. family household, workplace, see also figure 1) (Twine, 2015).

Eating practices, in general, can be considerably different if analyzed as part of daily routines that can occur inside and outside the household environment, at the workplace or at school/university. Eating practices with birthdays and Christmas parties. It is important to emphasize these settings in discussions about social practices in order to address their specificities properly, defining boundaries of research across time and space. As Jastran et al. (2009) describe, a routine of 'coffee in the morning', for example, combines food/drink (coffee) and time (morning), but the location, social setting, activity, mental processes, and physical condition can vary to a broad extent (e.g. quick coffee to go on the way to work versus long and relaxed coffee on weekends in a family setting). Considering this variety, eating practices are difficult to study since they are not necessarily coordinated and regulated in the same manner as other practice entities (Warde, 2016). For this study, we consider eating as being in the intersection with other relatively autonomous practices. They are a result of both, internal evolutionary pressures and the pressures that arise from the adjustment of other - sometimes even distant practices -, which will be discussed in the next section.

3.2 Theoretical framework: Dimensions and perspectives of the network of food practice analysis

In the following paragraphs, we will introduce the different categories of the framework, which will then be sketched in table 1.

Elements of practices

Elements are fundamental in the constitution of practice, since they represent the elementary unit and link within and between practices as entities (Shove et al., 2012). Elements are important since they will lead towards different dynamics of the network and relations to other practices.

For this study we follow Shove et al. (2012), that define practices as entities as being composed of three types of elements – stuff (objects, infrastructures and technologies), skills (understanding, knowledge, know-how, conventions on how to do things) and images (as ideas and aspirations, mental activities, emotions, motivational knowledge). Alternatively, the elements are named materials, competences, and meanings (Shove et al., 2012). The elements, which constitute the practice as an entity, are interdependent in distinct configurations and it is through the recurrent performances that these configurations are reproduced and sustained over time (ibid.: p. 7). In this sense, practices can emerge, persist and disappear when the links between

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their defining elements are made and broken (ibid.:21),

This model actively incorporates material elements as part of the analysis that refers to things, technologies and infrastructures (Shove et al., 2012). For instance, in vegan eating practices, materiality is involved regarding vegan food itself (vegetables, fruits, cereals), but also instruments to prepare it (e.g. knives, mixer), cookbooks, kitchen space, vegan nutrition guides as well as shopping and eating out infrastructure (Twine, 2018). The material arrangements and their use are especially relevant when analyzing the ecological sustainability of consumption (Schäfer et al., 2012). Competence includes embodied skill forms, know-how, and technique (Shove et al., 2012). Referring to vegan practices as an example, this could mean nutritional knowledge, knowledge of animal-derived ingredients, label recognition or competence in using new machines to prepare e.g. smoothies or spreads (Twine, 2018).

Social meanings, as the last constitutive element of practices, are the basis of people's motivations; they allow people to make sense of their practical actions. They can be associated with pleasure, progress, strength, health, and fitness, but also with responsibility for childcare or 'doing family' (Twine, 2018). In different settings, we can expect different combinations of elements linked to each other. Using the overall food practice 'having lunch' as an example, we can exemplify these variations as represented in the following figure (Figure 1):

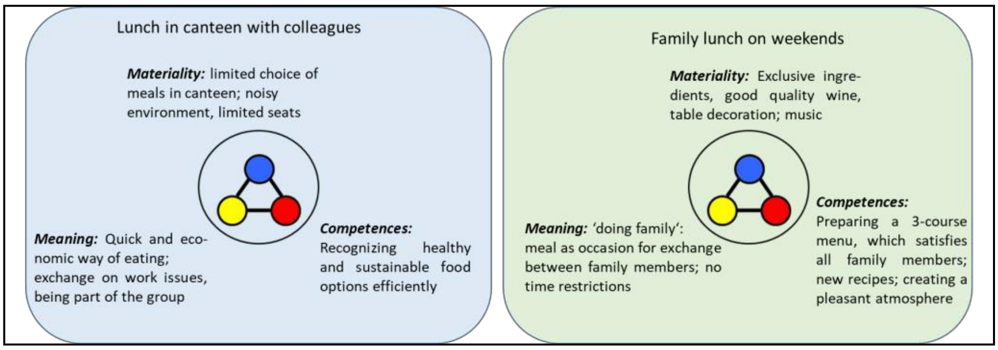

Figure 1. *Variations of the practice "having lunch";* ***Source:*** *inspired by Shove et al. 2012*

While daily lunch with colleagues might be dominated by meanings as efficiency and allowing exchange about work issues, lunch on weekends could be associated with the meaning of 'doing family' (which includes a long meal with something special being prepared). Having lunch with friends outside could be linked to showing belongingness to certain social groups (status amongst peers). Depending on the setting and the meaning attached to the respective variation, different material elements and competences are also involved (e.g. selection of possible meals in a canteen or a snack bar versus supply in a high quality restaurant; competences to cook 'a quick and healthy' meal during the week versus a fancy meal on weekends, which satisfies all family members or impresses guests).

Going through these variations and the elements involved in a systematic way enhances the understanding of the challenges involved considering certain changes (as e.g. eating vegan or only eating organic/regional products).

Complexes of practices

The second level of the framework aims to understand the relation between the core practice – in this case eating – and closely connected with other practices which are performed in a temporal sequence or are linked in co-dependency. Describing this phenomenon, two different terms are used with slightly different connotations: integrative practices and complexes of practices. Integrative practices are practices that presuppose each other because each performance affords competence in at least several others (Warde, 2016).

In the discussion about consumption practices, Shove et al. (2012), use the term 'complexes of practices' to refer to practices that bundle together in "stickier" forms of co-dependence in which aspects such as synchronization, sequence, proximity or necessity to co-exist are important and play a crucial rule to enable the performance of practice. On a conceptual level complexes of practices and integrative practices describe co-dependent practices that entail dynamics that cannot be reduced to the "content and form" of the individual practices which they are composed of (Kuijer, 2014; Jensen, 2017).

Eating and food-related practices in this perspective are connected in complexes, since eating practices cannot be understood without taking into account practices of food acquisition, preparation, cooking, and habits of have a meal, which is deeply embedded in social relations (Brückner and Caglar, 2016; Halkier and Jensen, 2011; Warde, 2005). Figure 2 exemplifies the sequence of typical household food- practices.

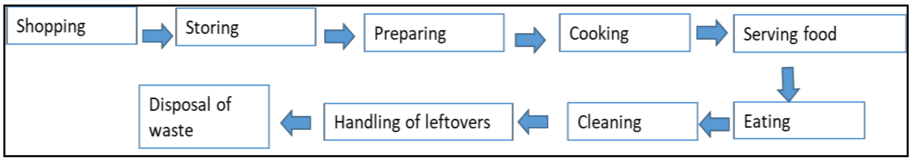

Figure 2. *The Sequence of food-related practices in the household,* ***Source:*** *Original*

This suggests that preceding processes must take place such as obtaining (shopping) and preparing (cooking) food to enable the performance of food consumption (eating) itself. Thus, those represent and are part of complexes of food-related practices encompassing interdependent constitutive elements, such as materials, meanings and competences (Shove et al., 2012). E.g. meanings of sustainability can be part of all the connected practices in this complex, influencing shopping, preparing and storing food as well as dealing with leftovers in a reflected way. Different authors also identified similar patterns and sequences which constitute complexes of food-related practices, such as ways of provisioning, storing, cooking, eating, waste sorting/disposal, managing leftovers, etc. (Gojard and Véron, 2018; Leray et al., 2016; Halkier and Jensen, 2011; Schanes et al., 2018; Wahlen, 2012; Evans et al., 2012; Devaney and Davies, 2017; Cappellini and Parsons, 2013). The main characteristics of food complexes, therefore, are inter- or co-dependency of the connected practices. Identification of these close relations and dependencies helps to understand how other – dependent – practices are influenced if a change in one of them occurs.

Bundles of practices

At the next level of the framework, we explore the bundles of practices interconnected throughout time and space (Hiu, 2016). In contrast to co-dependency of practices, the central characteristic of bundles is sharing and/or competing for space and time with the performance of the 'main' analyzed practice. We suggest this differentiation (which is not done by most authors) to avoid confusion between complexes and bundles, especially for empirical analyses.

Jensen (2017), inspired by Schatzki (2009), refers to bundles of practices as practices that are linked to each other, but they are not entirely, strictly or necessarily co-dependent of others. They represent loosely coupled practices

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that are usually carried out within the same site or setting and shape each other. Differently from complexes of practices, it seems less clear how to empirically trace bundles of practices that are more loosely coupled, but nevertheless interrelated (Jensen, 2017). In our case, we adopt Jensen's (2017) perspective and explore, how eating connects in bundles with non-food practices across time and space. Spurling et al. (2013:37), argue that "Eating interlocks with other practices—for example, it is synchronized and sequenced with other practices such as caring for a family, socializing, working, traveling and even watching the television".

For example, for people who live with spouses or families, the schedules of each family member's obligations (both work and non-work) typically shape their eating routines (Jastran, et al., 2009). As Jastran et al. (2009) found in their study, for parents of young children it is often simplest to eat at times that are best for their children. Eating is also related to forms of 'doing family' (Morgan 2011:5), since eating routines are embedded in family schedules (ibid.), and parenting modes (Brannen et al., 2013). Eating and food routines are also interconnected with other domestic practices, such as homemaking and childcare (Nicholls and Strengers, 2015; Jastran et al., 2009).

Eating is also part of practices such as 'doing leisure' (Morgan, 2011). Eating, for example on weekends or non- workdays, often means enjoying more relaxed meals (Jastran, 2009). Eating a meal or a snack might also happen at the same time as other practices such as relaxing in the evening (e.g. eating popcorn when watching a movie) (Jastran et al., 2009:6, Twine, 2015) or picnicking while relaxing in the park. These leisure activities, which are taking place in the same spatial and temporal sphere, shape eating practices and vice versa. They share a number of elements, in this case, e.g. the meaning of 'fun, enjoyment and relaxation'.

Similarly, eating practices are connected in bundles with practices of 'doing work' (Morgan 2011: 5). According to Jastran et al. (2009), eating routines are embedded in social contexts such as work (e.g. 'coffee before work', 'lunch with colleagues'). Work shapes eating routines in many ways, in the sense that work schedules, whether fixed or variable, influence the regularity – or irregularity - of eating episodes (ibid.). Warde et al. (2016) note how scheduling and location of working practices, for example, strongly determine eating practices. In these cases, it seems that eating practices themselves are not treated as the most prioritized practice, as Pfeiffer et al., (2017) noticed. Consumers nowadays tend to fit meals outside the home into their dense schedules and in between all other kinds of appointments instead of scheduling their days around meals, in order to save time and effort. Doing work in an expected way, in this case, competes with the desires of having more relaxed (and maybe healthier meals), the former being the dominant practice.

Identification of connections in bundles enhances the understanding of challenges of establishing certain novel food practices in contexts where other practices dominate or strongly influence the practice under investigation.

Nexus of practices

The next category of the framework takes up nexuses of practice, meaning practices that are indirectly connected to each other or are in the intersection of others. For example, practices are similarly inseparable from their mobility (Hui, 2013: 892). Mobility is an interesting case since it connects with shopping, work, habitation and so on (Spurling et al., 2013) and -by doing this - interconnects these practices indirectly. This perspective can also be applied to eating and its relationship to other practices via transporting and mobility practices (Leray et al., 2016).

Mobility e.g. refers to transport for purchasing food from shops and take-aways or to move to a restaurant (Quist et al., 1998). To enact the performance of eating out, is impossible without preceding acts of mobility (Speck and Strassner, 2017:8), just as well as shopping practices necessarily afford some type of transportation. Mobility is acting as a practice in the intersection between several daily practices and thus serves as a 'nexus' that links different, seemingly unrelated, practices. Food shopping, for example, many times is combined with other practices as bringing children to Kindergarten or on the way back home from work. The normal route to these places might, therefore, have an influence on the selection of shopping facilities for food, determining, for example, if organic food products are available in adequate quantity and quality. Vice versa, there might be an influence of the shopping practice on the choice of transport also to Kindergarten/school/work: Knowing that heavy products will have to be transported, the car might be chosen, even if this would not be necessary for accompanying the child on its way to Kindergarten or for the way to work. Identification of this kind of nexuses enhances a deeper understanding of why certain practices are carried out in the way they are (e.g. going to work by car), even if this might not appear to make sense at first sight.

Impact of the environment (context) on practices

As the last category of the framework, we deal with the influence of the context in shaping practices. As Schatzki et al., (2005) points out, practices are always situated in time and space and unfold in site ontologies, shaped by the particular historically given conditions of specific localities and particular moments. According to Kemmis and Grootenboer (2008), practices are mostly regulated by circumstances and conditions that are 'external' to them – more specifically by pre-existing cultural-discursive, material-economic and social-political arrangements which, as Kemmis et al. (2012) point out, give the form and substance to 'practise a practice'.

Back to our example, even though eating does involve individual choice, the choice is deeply conditioned by the context in which it occurs (e.g. rural, urban, cultural customs, social norms, etc.). Social practice theory provides theoretical guidance for studying the social nature of eating, approaching it as being integrally linked to context (Delormier, et al., 2009). Eating events have emerged in the social, temporal, economic and cultural organization of everyday life (Twine 2015). This means that food practices are clearly embedded in materiality (housing, technology), infrastructure (transport, amenities) and cultural notions of appropriateness (ideas about proper eating, care, and convenience) (Paddock, 2017).

Social contexts are integral in shaping food and eating patterns of population and groups (Delormier et al., 2009:224). More specifically, culture is responsible for shaping food preferences in ways that are habitual and automatic (Johnston, et al., 2012). The practices of eating vary both, culturally and historically because its degree of a social organization also shifts within different social and economic conditions or complexes (Warde, 2013). Eating is associated with social norms which also include aspects related to which food is viewed as being adequate for eating (e.g. meat from horses, dogs, frogs, insects) and how food should be prepared (e.g. warm dishes for breakfast or not) (Douglas, 1972).

Previous studies point out that changes in the social organization of eating over the last decades occur, because of processes of individualization and informalization and also refer to forms of cultural changes related to family structure, employment, living conditions and lifestyles (Holm et al., 2016; Warde et al., 2007). Eating and different types of what can be considered as a 'typical day' of dietary intake are deeply embedded in the contexts of home and school as well as relationships with parents and peers (Backett-Milburn et al., 2006; Jastran, et al., 2009).

Routines related to eating reflect what people have learned is appropriate, expected, or desirable in their cultural

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and social contexts, e.g. the timing, foods, and settings for daily 'breakfast', 'lunch', and 'dinner' plus 'snacks' (Jastran 2009). Eating can be seen as part of the materiality of the social itself featuring clearly in the everyday performance of social relationships (Twine 2015), thus "we should not neglect the social shaping of the elements of practices or the often substantial barriers to individual change" (Speck and Hasselkuss, 2015:2).
Table 1 summarizes the findings and makes a suggestion on how the connections on different levels can be operationalized for empirical research by reflecting a set of questions, following a 'zoom out'-perspective.

3.3. Analysis of the challenges of changing food practices

The developed framework can be used to analyse existing networks of practices by reconstructing the connections on different levels in a systematic way. Furthermore, it can be applied to analyse changes in practices that have taken place in the past or for estimating the challenges and consequences of changing certain practices that are claimed to be necessary e.g. based on sustainability or health arguments. In this section, we want to outline briefly how the different levels of connections can be considered if a change of practices is at the center of analysis.
Change occurs at the level of reordering the elements through which practices, as entities, are organized (Shove et al., 2012; Warde, 2005). This means that changes might occur, when one or more of the elements, holding together a practice, shift or disappear (Sahakian and Wilhite, 2014) or when the connections between elements are broken. Novel combinations between new and existing elements, such a newly acquired competences or new technology or equipment (e.g., household devices as mixers allow people to devote less time to cooking) lead to innovative practices (Warde et al., 2007). In these processes, elements shape each other (e.g., eating vegan often requires different competences than just to consume new types of food). Using eating as example, alterations of the meaning (more healthy, ethical, joyous), competences of following certain food styles (Asian style, vegan, etc.) or shifts in the materiality of food (e.g. introduction of new ingredients, offers of organic/vegan products in the normal supermarket or in canteens), will have implications, not only for the whole practice itself, but also for routines related to it.
Change can occur on the complex level since a practice can change "as neighbouring practices change" (Watson, 2012, p.492). Considering co-dependent practices in complexes, this also implies that changes in one practice can induce changes in adjacent practices and might affect how multiple practices are performed (Spurling et al., 2013; Sahakian and; Wilhite, 2014), for example, because they share elements (Gram-Hanssen, 2011, p.75).

Change might also occur in bundle connections. As pointed out before, eating routines are embedded in a social context such as work and family schedules/settings (Jastran et al., 2009). E.g. eating practices might change when family arrangements do (ibid.). Social and historical studies show that changes in the temporal patterns of eating (e.g. three meals a day) are linked to shifts in the institutional arrangements of family life, households, and working hours (Southerton et al., 2011). Changes often are associated with events of rupture (Warde 2016) or due to life- course events such as changing work patterns, cohabitation, and the birth of a child, which lead to reshaping cooking and eating practices (Paddock, 2017; Schäfer et al., 2012).
Changes in practices require attention not only for specific and located practices (e.g., eating) but also for those to which they are connected across both space and time (e.g., of working, leisure, parenting) and others that might be seen as 'seemingly unrelated' (Spurling and McMeekin, 2014, p.90).
An example of interconnected changes might be buying more organic food because of the birth of a baby. This might imply to change shopping habits since the (bigger) organic store is further away. This could lead to going

there not by bike but with public transport or car. So, while one of the changes is towards more sustainability – eating more organic – the other one is moving towards less sustainability – using the car more often (or even buying a car for 'safe transport of the child'). Both can, however, be explained with the overarching meaning of 'being a good parent' and fulfilling societal expectations in this regard. Once the car is bought, a lot of 'unrelated' routines might change (using it for weekend trips, holidays, etc.) (Schäfer et al., 2012). This example illustrates that "practices are connected together in systems, and so changing how one practice is organized will have implications for all the others that it is connected to" (Spurling et al., 2013:29).

Additionally, the variability of the contexts in which practices are carried out opens up spaces of uncertainty that can lead to changes in practices. For example, in food crises (as in the case of mad cow disease), an event can create uncertainty, leading to a shift to alternative, more sustainable consumption practices (Brand, 2010).

The next section will propose the framework for future empirical analyses of networks of practices.

4. Using the conceptual framework for empirical analyses

Using insights of the social practice approach, table 1 presents a conceptual framework developed to operationalize empirical research, which is interested in detecting the complexity of single practices being embedded in networks of practices and being shaped by the environmental context. As far as we know, this is the first attempt to combine insights from the above-named strands of literature, referring mostly to Reckwitz (2002), Schatzki (1996) and Warde (2013, 2016), as well the material understanding of Shove et al. (2012). Our framework uses a 'zooming out' perspective (Nicolini, 2012; 2009), starting with the single practice of eating as the smallest unit and gradually reconstructing connections on different levels, described below.

Table 1. *Conceptual framework for the analysis of a network of practices*

Dimension	Descriptio n	Questi ons
Elements of practice	Practices are constituted by elements, which are linked to each other in daily performance: material elements, competences, and meanings (Shove et al., 2012). Different practices can share elements in common (Shove et al., 2012). Variations of elements of practices canbe differentiated depending on the setting (e.g. private home/ workplace; weekend meal/daily meal)	• Which main material elements (e.g. tools, infrastructure, 'stuff') are part of the practice under investigation? • What are the main competences/ practical know- how necessary to enable the selected practice under investigation? • What are the meanings associated with the selected practice under investigation? • In which variations are those elements combined and connected to each other? • Which elements might be in the intersection of multiple practices?

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Dimension	Description	Questions
Complexes of practices	Complexes of practices describe very close connections between different practices in a 'sticky' way, often including the necessity of co-existence (Shove et al., 2012). Practices can be connected in complexes sharing certain elements (Shove et al., 2012). They can also be linked in temporal sequences, one being the precondition for the performance of the next one (co-dependency of the practices).	• To which other practices is the selected practice directly connected in form of a complex (co- dependency with other practices)? • Which elements are shared by different practices within the complex of practices? (e.g. 'food' as material element or 'health' as a meaning) • Is the selected practice part of a sequence of interconnected practices that enable each other's performance?
Bundles of practices	Practices can be loosely connected to each other in bundles, not being entirely, strictly or necessarily co-dependent of each other (Jensen, 2017). They are usually carried out within the same site or setting (spatial intersection) or time (temporal intersection) and shape each other (Jensen, 2017).	• To which other practices, that are carried out in the same setting/ at the same time, is the selected practice loosely connected? How does this connection shape the practice under investigation? • To which other practices is the selected practice loosely connected in a temporal sequence? (without co-dependency, beyond the complex of practices) e.g. giving food to the child, washing the child. • Does the selected practice compete with others for attention and priority?
Nexus of practices	Nexus describes indirect connections beyond complexes and bundles. It involves the connection between 'seemingly unrelated' practices via practices that are in the intersection of different practices (Spurling et al., 2013) (e.g. mobility practices).	• Is the selected practice indirectly connected to other complexes or bundles of practices via intersecting practices (nexus)? • Which practices are at the intersection of others? • What influence does nexus of practices have on the main practice under investigation?
Context of practices	The macro context influences the characteristics and dynamics of practices as an entity over longer periods of time. Practices are regulated by circumstances and conditions that are 'external' to them, more specifically by pre-existing cultural-discursive, material-economic and social-political arrangements (Kemmis et al., 2012). The influencing context may be related to global trends (as e.g. individualization, globalization, division of labor), social norms (e.g. being a responsible parent) and cultural specifics (e.g. high value of certain foods).	• Which global trends have an influence on the performance of the selected social practice? • Which social norms have an influence on the performance of the selected social practice? • How is the selected practice influenced by cultural specifics? • What kind of social/political configuration specially shapes the practice under investigation? • In what kind of material-economic context the practice under investigation is performed and what are the broader material arrangements involved (e.g. 'systems of provision', infrastructure)?

Source: *Original*

Based on 'zoom out' perspective, it is possible to follow the associations between practices and to detect the connections between practices by following them in space and time (Nicolini, 2009).

Translating this into our model step by step implies that we should:

- First, identify the nature of the 'core' practice under analysis.
- Define the elements (meaning, material, competence) that constitute the 'core' practice as an entity under investigation,
- Identify possible and common settings, where, when and with whom the practice is performed,
- In sequence, reconstruct the network of practices gradually, starting from a single practice, systematically checking the other levels of connections between practices (complexes, bundles, nexuses) across time and space,
- Identify the relevant context conditions shaping practices as an entity,
- Using the questions posed for reflection on the connections in the network of practices and 'drawing a holistic picture' (visualization might be valuable).

We propose that this framework can be particularly useful for:

- Empirical analyses of existing networks of practices (the basis for formulating guidelines for interviews, observations, etc.). It could, for example, be used for comparing the structure of the network of practices in different contexts (urban/rural; different national/regional cultures)
- Analyses of changes that have been taken place in the past, comparing e.g. the structure of social practices networks (elements, interconnections between practices, etc.) before and after a change
- Identification of challenges for future changes of practices by systematically reconstructing possible changes of interconnections in an anticipatory manner.

5. Conclusions

The main scope of this paper was to propose how to approach relations and connections between practices in a more systematic way in empirical analyses. We addressed the challenge to determine the levels of connectedness and relations of practices and how they could be understood as part of a broader network of interrelated practices, using eating and food practices as an example.

From our knowledge, the analytical framework proposed in this paper is the first attempt to operationalize the diverse concepts from SPT literature for empirical analyses of networks of practices. So far, existing literature deals with these relations without addressing the different levels of connections properly or distinguishing them by using clear definitions. In contrast to the methodological approach of Higginson et al. (2015), who suggest quantitative network analysis, we present a qualitative analytical framework which allows a step-by-step reconstruction of connections, that encompass complexes, bundles, nexuses and the context of practices, applying a 'zoom out' perspective. This type of re-construction can be the basis for reflections regarding the complexity and embeddedness of existing social practices and the challenges of changing them.

Change of practices from this perspective can be understood as depending on the strength of the relationship between interconnected elements and their level of dependency. Using the example of food practices, this paper also gives an idea that eating and food-related practices are rich phenomena that can be analysed at multiple levels. The potential and usefulness of the framework can only be proven if it is applied in empirical research. The team of authors is planning to use the framework for empirical research in the field of food practices.

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However, it can also be applied to other areas of daily routines as mobility, energy use, etc.

As outlined above, the framework can be used for analyses of existing networks of practices, understanding changes that have already taken place or for identifying challenges for anticipated necessary changes.

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The Role of Local Governments in Food Waste Prevention – Insights from Selected German Municipalities

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Abstract
Food waste prevention has gained greater relevance on the political agenda over the last decade. However, the involvement of municipal actors in pushing the issue forward has been comparatively limited. Based on the cases of the German cities of Munich and Cologne, this paper examines the possible approaches to prevent food waste at the municipal level and their relevance on the local agenda. It first proposes a definition of local food waste prevention policies and presents an overview of options for municipal actors. Based on the analysis of own interview data and secondary sources, it then applies Kingdon's Multiple Streams Framework to gain insights on the agenda-setting processes in the two cities concerning the issue. The results suggest that policy entrepreneurs, a strategic framing, and networking with other political levels favour the rise of food waste prevention on the local agenda. The main hindering factors identified are problem load and budgetary constraints, as well as the lack of strong political interest groups and a perceived spatial mismatch between problem and solutions. The findings provide starting points for (i) the further investigation of the so far under-researched potentials and limitations of municipal food waste prevention as well as for (ii) local (network) activities which strengthen food waste prevention on the level of municipalities.

Keywords: Food Waste, Waste Prevention, Municipalities, Policy, Agenda Setting

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1. Introduction

1.1. Food waste prevention on the political agenda

With an estimated 1.3 billion tonnes of food, equal to about one-third of all food produced, going to waste globally each year, the challenge of food waste prevention has gained greater relevance on the agenda of policy makers, businesses, civil society and research over the last decade (FAO, 2011; European Court of Auditors, 2016; Lipinski et al., 2017). In its resolution on "reducing food waste, improving food safety" in 2017, the European Parliament underlined the significant role of municipalities and local stakeholders to "implement food waste reduction and prevention programmes", "reduce food waste in public establishments" and in "providing information and assistance to citizens on how best to keep and/or use food in order to prevent and reduce food waste" (61, 88, 133).

At the same time, food waste prevention is both a new and voluntary task for municipalities that competes for attention and personnel and financial resources with a wide array of other issues. Besides, policy actors first need to recognise their own scope for action. According to research on waste prevention in Bavaria, as much as half of the municipalities consulted perceived their potential to prevent food waste to be low or even very low (Hutner et al., 2017). Furthermore, major policy processes impacting food waste in Germany are not anchored at the level of municipalities but at the state, federal and European level, with up to 80 percent of waste-related policies being set at the European level (AWM, 2017). Hence, food waste prevention is not the most likely candidate on the crowded agenda of local authorities. Yet, decision-makers in some municipalities across the globe have recognised food waste to be of local importance (Magarini et al., 2018; WBA and C40, 2018). Consequently, there is need to understand how food waste and it's prevention appear as "a 'public' problem worthy of [...] attention" for local authorities (Wu et al. 2012, p. 13).

In this paper, we examine the field of local food waste prevention through case studies of agenda setting in two German cities, Cologne and Munich. Based on Kingdon's Multiple Streams Framework (MSF) (2011 [1984]) the paper analyses the factors that contributed to or rather hindered the process of setting food waste prevention on the agenda in these municipalities. This research contributes to closing knowledge gaps in the following ways:
(i) define local food waste prevention and discern its current status in the selected cities; (ii) suggest enablers and hindrances to agenda change regarding food waste prevention on the local level; (iii) formulate directions for further research.

1.2. The cornerstones of municipal food waste prevention

Although the debate about food waste definitions, drivers and suitable responses is ongoing (see e.g. Chaboud and Daviron, 2017), it is undisputed that it has substantial environmental, economic, social, cultural and health- related impacts (Kummu et al., 2012; FAO, 2013; Eberle and Fels, 2016; Lipinski et al., 2016; Hanson and Mitchell, 2017; MUFPP, 2018). In line with German and European policies, the term food waste in this paper refers to the entire food supply chain, that is, from primary production to consumption (BMEL, 2019; EC, 2019). Further, local or municipal food waste prevention policies are understood as activities, practices, or by-laws put into effect or adopted by a local government which, ultimately, lead to the reduction or prevention of food waste.[1]

Since causes of food waste span both public and private realms, the options of food waste prevention policies for local authorities can be structured according to the role public actors play vis-à-vis private actors. In the framework which Kern et al. (2005) and Bulkeley and Kern (2006) developed regarding local climate change policy, municipalities can take four different, albeit sometimes overlapping, roles: (i) as consumers and role models; (ii) as enablers and facilitators; (iii) as service providers; and (iv) as regulators and planners. Table 1 provides an overview of selected policy options for food waste prevention in municipalities structured along those roles, based on recent literature (Kranert et al., 2012; Marthinsen et al., 2012; Priefer et al., 2013; Galda, 2014; City of Milan, 2015; Jepsen et al., 2016; Magarini et al., 2018).

Table 1. Selected options for local food waste prevention policies. Own elaboration based on Kern et al. (2005).

Role of Municipality	Consumer and Role Model	Enabler and Facilitator	Service Provider	Regulator and Planner
Food Waste Prevention Policy Options	Integration in public procurement	Educational and awareness raising campaigns	Household campaigns	Integration in Food System Planning
	Capacity building for public employees	Support of citizen and business initiatives and innovation	Adjustment of cost for organic waste disposal	Tax incentives for food donation
	Campaigns in public institutions	Support of food redistribution organisations		
	Canteen reorganisation	Funding for research		
	Food waste sensitive catering during public events	Enabling collaboration across food supply chain		
Overarching	Integration in local food, waste prevention, education, climate, and sustainability policies			

Overall, local authorities with relevance for food waste prevention are local administration departments, city councils, public waste authorities and also food councils if public actors play an active part therein. Depending on the local context, the relevant municipal departments involved are

[1] Adapted from Schwartz (2016) writing about municipal climate change policies

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food production (agricultural departments), distribution (market departments), waste (environmental departments), education (environmental and/or school departments) and consumption (public purchases departments) (Magarini et al., 2018).

In accordance with the so-called waste hierarchy, this paper focuses on the prevention of food waste ahead of its management or better valorisation, as shown in Figure 1 (Hanson, 2017). The better valorisation of food waste, for instance through separate organic waste collection and subsequent anaerobic digestion and composting, can certainly count as an important improvement in waste management and a contribution to climate change mitigation (see e.g. WBA and C40, 2018). However, these measures do not reduce food waste quantities and as such are not counted as food waste prevention. Based on experiences with waste incineration, such measures could even conflict with efforts in food waste prevention (Bogumil and Holtkamp, 2006; also see Lamping, 1998).

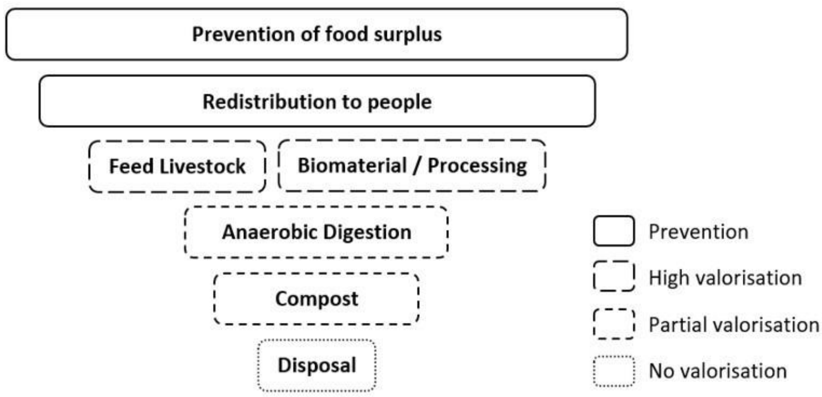

Figure 1. The food waste hierarchy. Own elaboration based on Hanson (2017).

Furthermore, the focus of analysis lies on concrete local policies which state the prevention of food waste as an intentional or secondary goal during the agenda-setting phase. This generally excludes what Dupuis and Biesbroek (2013) call contiguous and contributive policies that primarily fulfil other goals while having an unintentional effect on the field of interest. As a case in point, the fostering of short supply chains in urban food systems may have an unintended (positive) effect on food waste quantities, but most-often pursues other goals such as closer consumer-producer relations or the promotion of local and regional businesses (Schikora, 2017). Due to their comparatively vague link to the issue, such policies are less suitable to study the rise of food waste prevention on local agendas.

2. Methods

2.1. Theoretical framework: Agenda setting and the Multiple Streams Framework

Policymaking in local authorities is characterised by multiple constraints, including limited jurisdiction vis-à-vis higher levels of government and scarce resources. At the same time, there is a practically infinite number of potential issues that require attention and may be addressed through local political action. The literature focusing on problem definition and agenda setting is interested in how different policy problems competing for attention are defined, linked to policy alternatives, and gain or lose agenda status (Jones and Baumgartner, 2005; Baumgartner et al., 2014; Jenkins-Smith et al., 2014). Birkland (2007) defines the agenda as "a collection of problems, understandings of causes, symbols, solutions, and other elements of public problems that come to the attention of members of the public and their governmental officials" (p. 63). The agenda hence is constituted by concrete policy proposals, as well as by more general understandings about the importance of a problem and how it should be addressed.

Kingdon (2011) has given rise to the most prominent and still growing body of literature explaining agenda setting and alternative policy selection as a confluence of three streams. In short, the problem stream considers how various issues get defined as problems to be tackled and how these catch the attention of relevant policy makers. Possible attention attractors are new indicators about the magnitude of a problem, prominent focusing events, as well as policy feedback that sheds light on malfunctions of existing policies or practices (Liu et al., 2010; Kingdon, 2011). The policy stream concerns the many possible policy solutions – alternatives – that are continuously developed, discussed and discarded in policy networks. Certain attributes make an alternative more or less likely to survive and subsequently rise on the respective agenda. The survival criteria of a policy option are stated as technical feasibility, acceptance in the policy community, and anticipated future constraints on the way to implementation (Kingdon, 2011; Herweg, 2015). Thirdly, the politics stream considers political developments which lead decision-makers to be more or less receptive to certain problems or solutions. Among these count the overall public opinion, pressure from interest groups, as well as personnel turnover in government or local agencies (Cairney, 2009; Henstra, 2010; Liu et al., 2010).

Changes in the three streams can either act as a constraint or as an impetus for agenda change (Kingdon, 2011). Agenda change becomes likely when at least two streams are ripe, that means, favourable towards a certain policy issue. Dedicated policy actors, so-called policy entrepreneurs, must seize such windows of opportunity. Policy entrepreneurs are key in agenda setting, as they "are willing to invest their resources in pushing their pet proposals or problems, are responsible not only for prompting important people to pay attention, but also for coupling solutions to problems and for coupling both problems and solutions to politics" (Kingdon 2011, p. 21). Research on local environmental policy making affirms this important role of policy entrepreneurs within the administration or at a high political level in setting issues onto the agenda (Bulkeley and Kern, 2006; Schreurs, 2008).

Since its development and application on national-level agenda setting in the policy fields of health and transport, particularly research by Zahariadis (2007), Herweg (2013) and Herweg et al. (2015) has expanded on the MSF's critiqued large "untapped potential for theoretical and empirical advance" (Cairney and Jones 2016, p. 56). The framework has been applied in comparative policy analysis

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(Béland and Howlett, 2016), to different policy levels including local policymaking (Henstra, 2010; Liu et al., 2010; Cairney and Jones, 2016; Rawat and Morris, 2016 and has also provided the basis to understanding agenda stability, that is, why certain issues do not rise (further) on the agenda (see Gladwin et al., 2008; Herweg, 2013, 2015).

2.2. Case study method and selection

In a young research field such as local food waste prevention, case studies are apt for studying a small set of units intensively and thereby gaining insights for the further study of similar cases (Gerring, 2007; Vogel and Henstra, 2015). Munich and Cologne provide two cases of large cities in Germany (over 1 million inhabitants) where food waste prevention has had some degree of agenda success and where current and past activities addressing the issue are found. In Cologne, an educational campaign specifically targeting food waste prevention in schools, called "It's a pity" (Schad dröm), was launched under the leadership of the Environment Agency in 2012. A subsequent phase of the project starting in late 2017 primarily addressed cooking skills and food knowledge gaps among students by organising classes with young gourmet chefs. Further discussed, but not (yet) implemented food waste prevention actions include changes in school catering and canteen management and the integration of food waste in the food strategy by the food council[2].

In Munich, food waste prevention achieved agenda success as a minor element within the Food Education Concept adopted by the City Council in late 2017, which provided funding for ten mobile cooking units with accompanying educational material for secondary schools. Further, two school canteens were reorganised in 2018 to take food waste prevention into account and the issue is also addressed in the canteen management in the Department for Health and Environment. Several other policies on the institutional agenda, and therefore per definition not yet implemented, include the integration of food waste prevention in public procurement, food surplus redistribution in public canteens, as well as a possible food waste prevention campaign directed at households by the public waste management authority. In both cities, smaller funding for private actors' food waste prevention initiatives is generally available, for instance as part of Agenda 21 or other environmental funding schemes that organisations can apply for at the respective department (Ratzesberger, 2016; Taste of Heimat e.V., 2016).

Overall in these measures, the role of municipalities as indirect[3] consumers is predominant, accompanied by their role as enablers and facilitators. Measures tackling food waste prevention through regulation or planning authority are absent and the municipal waste management authorities have so far acted as enablers, but not concretely addressed food waste prevention through campaigns or other measures. Acknowledging that the cases of Munich and Cologne lie on one end of the spectrum regarding local food waste prevention and are hence not representative of German municipalities overall, we build on the extreme case method for probing possible causes of how food waste rises on the local agenda

[2] The food strategy for Cologne was published in May 2019 after the conclusion of research and contains one chapter on food waste prevention.

[3] Since e.g. in school catering the pupils are direct consumers of the meals.

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(Gerring, 2007).

2.3. Data generation and analysis

Using a variety of data sources on the selected cases allows the researcher to consider contextual factors and unanticipated aspects to a greater extent than in larger studies generating quantitative, aggregated data. This corresponds to our objective of understanding two cases in depth while generating hypotheses for further research (George and Bennett, 2005). Firstly, we scoped the field of municipal food waste prevention through three helicopter interviews with experts in Germany, followed by seven semi-structured expert interviews with two officers in municipal departments, one staff of a waste management provider, one City Council member, and three members of civil society or media organisations. The selection of interview partners was based on their involvement in activities or their relevant position regarding the issue of food waste prevention, as well as their diverse perspectives on local policymaking in the cases at hand. This purposeful selection is based on the function of experts in case study research, who are not selected for representativeness but rather need to have particular knowledge about the area of interest (Eisenhardt and Graebner, 2007; Treib, 2014). The interviewees were either identified through personal referral or online research and contacted via e-mail, outlining the scope of the study as well as the reason for their targeted address.

All interviews were carried out in October and November 2018 via telephone and the questions covered the status of food waste prevention on the agenda in the city overall, in the respondents' agency or organisation, as well as the factors potentially explaining this status. In the course of the interviews, follow-up or probing questions were added to ensure that the key factors identified in the literature would be addressed. Six interviews were recorded and subsequently transcribed. One interview was not recorded due to time and technical constraints. For this case a recollection of interview notes from memory was written (in line with the recommendations by Kaiser, 2014). During the interview analysis, the principles of open, systematic, and theory-led qualitative content analysis were followed (Kaiser, 2014). We indexed interview sections along the operationalised factors of agenda setting found in the MSF literature, as set out in Table 2.

Table 2. Factors impacting local agenda setting in the Multiple Streams Framework applied to food waste.
Own elaboration based on Liu et al. (2010), Kingdon (2011), Herweg (2013).

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	Factor	Operationalisation	Example(s)
Problem Stream	Indicators	Numbers or statements conveying the magnitude of food waste as a problem	Per capita waste rates; assertions about food waste as a big, minor, or small problem
	Focusing or anchoring events	Occasions that put a spotlight on food waste and are registered locally	Report publications; public events related to food waste; natural events
	Feedback	Evidence that local policies impact food waste	Evaluation of existing public procurement practice
	Framing	Key causes of food waste as expressed by respondents and in policy documents	Emphasis on the food or waste dimension; responsibility put on specific food chain actors
Policy Stream	Technical feasibility	Mention as criteria for success or failure of policy proposals	Expertise of canteen staff to implement waste prevention measures
	Value acceptance		Sufficiency not accepted within current policy framework
	Anticipated future constraints		Conflict of measures with e.g. hygiene regulation
Politics Strem	Public mood	Mention of public opinion as positive or negative	Food waste prevention as a big or small issue 'in the city', 'among people'
	Pressure groups	Reference to civil society or private sector interest groups positioned towards food waste	Absence or presence of strong proponents demanding local food waste prevention action
	Personnel or electoral turnover	Mention of turnover leading to greater or less attention for food waste prevention	Party politics favouring food waste prevention; change of key decision-making figures
Policy Entrepreneur	Key figure related to local food waste prevention measures	Indications for particular commitment, persistence, expertise and access to relevant network	Personal and long-standing association with food waste; strategic position within local policymaking context

In cases where responses conveyed additional information that did not fit the framework, new categories were developed. The interview material was thereby condensed and structured into both theoretically deducted as well as empirically inducted categories. This allowed to identify the factors either working as enablers or constraints to the rise of food waste prevention on the local agenda.

At various stages of the research process, qualitative document analysis was carried out to supplement the interview data, probe for the information provided, as well as to gain evidence on factors not specifically stated by interviewees (Kaiser, 2014). The sources included administrative documents, minutes and results of council meetings, website texts, relevant policy documents such as waste (prevention) or food-related municipal strategies, journalistic material, as well as policy reports and studies on food waste. Searches of the online Council Information Systems (Ratsinformationssysteme) of Munich and Cologne provided further information on the role of food waste on the governmental agenda. Initial search words included Lebensmittelverschwendung, Lebensmittel, Verschwendung, Abfall, Abfälle, Wertschätzung, Ernährung and Vermeidung. Additional terms were added as more information about city-specific dynamics emerged (e.g. Schad dröm in Cologne or Ernährungsbildung in Munich). The time span of the documents consulted was set to include information from 2011 onwards, which is when food waste became more prominent in the German public and policy debate (Verbraucherzentrale NRW, 2017).

3. Results and Discussion

3.1. Enabling factors for food waste prevention agenda setting

The results, as presented in the following, suggest that the presence of policy entrepreneurs within local authorities, networking with higher political levels, as well as a strategic framing of food waste favour the rise of the topic on the municipal agenda. Indicators of the scale of the problem emerged as a relevant reference point for actors in the two cases, but according to our findings cannot be considered as a key enabling factor.

Champions inside local authorities

The first set of observations to make is the important enabling role of policy entrepreneurs in setting food waste prevention onto the local agenda. In both cases, a champion inside the administration investing time and energy into policy proposals of which they approve has been crucial in pushing food waste related alternatives forward. The policy entrepreneurs, respectively, in Munich's Department for Education and Sport and in Cologne's

Environment Agency also fit further criteria. They have a direct claim to be heard by policy makers due to their position within the administration. Their professional qualification as well as their large information network conveys a certain expert status regarding the proposed measures and both exhibit a considerable degree of persistence to fight for their pet issues.

Further, the policy entrepreneurs in the two cases demonstrated the potential to soften up a policy network and create more acceptance for policy issues and proposals over time. This is particularly important for cross- departmental food waste prevention measures, as the issue touches upon multiple municipal responsibilities. In Cologne, the policy entrepreneur's position in the Environment Agency demands persuasion skills, or at least collaboration efforts, with the School Department to alter school catering systems. In both Cologne and Munich, the integration of food waste prevention into public procurement is also a cross-departmental process that requires commitment and follow-up. From this perspective, the "slow progress of an idea towards acceptability" is the norm rather than the exception (Cairney 2018, p. 206).

Another finding concerning the impact of policy entrepreneurs is that the eventually successful policy

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alternative strongly reflects their primary area of commitment. In Munich and Cologne, the measures that most fit the understanding of municipal food waste prevention can be considered as the entrepreneurs' pet proposals or pet issues. These lie within the realm of education or food safety and show broadly similar understandings of the problem. Regarding education, the key concern is achieving an awareness shift concerning the perceived value of food as well as the reconstitution of fundamental food-related skills and knowledge among children and young adults, and by extension also their parents (Stadt Köln, 2012a; RBS, 2017). The underlying idea is that this task pertains to schools. Food education was once an integral part of curricula and could regain this status as pupils and students spend an increasing amount of (meal) time in educational institutions. Hence, schools would need to rediscover this educational mission in practice as well as in theory, and thereby contribute to preventing food waste. The policy entrepreneurs consequently advance proposals offering schools the practical means for this, namely, cooking classes, a student video clip production, mobile kitchen units or a free-flow catering system (Stadt Köln, 2012b; überkochen, 2018). Overall, these findings add to previous studies on the determining role of policy entrepreneurs in environmental policymaking (Mintrom and Norman, 2009; Pralle, 2009).

Policymaking dynamics on other governmental levels

A second set of observations concerns the extent to which policymaking dynamics on other governmental levels influence the local agenda-setting process. It was not originally included in the analytical framework, apart from the consideration that the compatibility with existing state or federal policies could be a survival criterion for alternatives in the policy stream (Liu et al., 2010). The analysis suggests that the linkages to state-level actors and initiatives played a significant enabling role for the rise of food waste prevention on the municipal agendas. In Cologne, the policy network from which food waste related alternatives emerge includes multiple actors outside the municipality such as the Ministry for Environment, Agriculture, Nature Conservation and Consumer Protection of North Rhine-Westphalia or the state's consumer advice centre, both active on the issue since 2010 (MULNV NRW, 2016; Verbraucherzentrale NRW, 2017). In Munich, the Bavarian State Ministry for Nutrition, Agriculture and Forestry fulfils a similar role by providing a shared platform through its Wir retten Lebensmittel initiative (StMELF, 2018). The connection of the respective policy entrepreneurs to these networks is reflected in the development of policy proposals, for instance by enhancing their technical feasibility or reducing their costs.

Framing

Our third observation was that policy frames as depictions of "what the problem is about, why it occurred, who is to blame and what can be done about it" (Knaggård 2016, p. 111) influence the agenda setting dynamics. A food- centred framing was more successful in both cities compared to a waste-centred frame insofar as the food frame linked the issue to education about the appreciation and right handling of food, nutrition and other topics of local relevance. As interviews have shown, alternatively framing food waste as predominantly a waste issue can still emphasize the need for strong prevention, comparable to the reduction of plastic or paper waste. A waste-focused framing however fits less well into an agenda focused on change, for instance, of a city's food system which is set through Cologne's prominent food council or Munich's Biocity (Biostadt) policy. Furthermore, making waste instead of food more visible potentially evokes negative associations (see Evans et al., 2012). Overall, either of these framings, and of course many more variations, can be a better fit to what is "already in the back of people's minds", and hence attach food waste prevention strategically to salient issues (Kingdon 2011, p. 103).

3.2. Hindering factors for food waste prevention agenda setting

The main factors constraining agenda setting found are problem load and budget constraints particularly in the administration, as well as the role or lack of interest groups from civil society or business side. Additionally, a territorial mismatch between the problem definition and policy alternatives hindered the rise of the issue on local agendas. Doubts about the effectiveness of awareness raising campaigns and anticipated constraints regarding the cost, acceptance or compatibility of potential measures played a hindering role regarding specific proposals.

Competition for available resources

A key constraint identified is the twin-set of problem load and budgetary limitations in public authorities. With diverging focus on either factor, respondents highlighted the stretched capacities to pay attention to the wide array of problems, particularly within the administration, but also by policy makers. A so far voluntary and comparatively new issue such as food waste prevention is hence crowded out. These two factors reflect the basic assumptions of the MSF that agenda space is limited and that issues compete to gain agenda access. They also confirm the expected importance of municipalities' financial and staff resources to put weight behind certain issues and to support their path onto the decision-making agenda. Acknowledging these factors however also invites the consideration that an emphasis on problem load can be used as an agenda denial strategy by actors in opposition to the issue. The problem itself is acknowledged but presented as impossible to deal with due to the limited amount of resources available, thereby omitting that this is in itself a decision in the hands of policy makers (see Cobb and Ross, 1997; Capella, 2016).

No pressure for local policy change

Overall, the case of Cologne shows that interest groups are not a necessary condition for setting food waste prevention on the agenda. Public attention for the issue initially rose mostly related to the broadcasting of the movie "Taste the waste" by Cologne-based film-maker Valentin Thurn in 2011, a situation seized by the local policy entrepreneur. In turn, the presence of strong interest groups suggests being particularly important to refocus policy makers' and the public's attention in a period when awareness for the issue is low. The interest groups sustaining food waste related activities in both Cologne and Munich are civil society groups that are strong in private and educational actions for changing personal behaviour and saving food surplus. While their activities are acknowledged and to

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some extent supported by local authorities, these groups however so far do not raise concrete food waste prevention demands towards local policy makers and mostly focus on activities targeting the consumer level. Additionally, they are also entirely volunteer based, which overall considerably reduces their power to develop or sustain political campaigns and conflicts.

As far as interest groups are concerned, local food councils could be expected to serve as a good platform for raising attention for the issue of food waste. However, we found that the limited capacities of Cologne's food council equally lead to a competition among issues to be raised, with food waste prevention rather taking a back seat compared to other topics such as the provision of regional or organic food. Next to their perceived strength and tenacity, interest groups championing food waste prevention must hence also match their demands to locally salient problems to increase the likelihood for agenda success.

Spatial mismatch between problem and solution

A third aspect to highlight among the constraints is the (perceived) territorial mismatch between the problem of food waste, more substantial solutions to it, and local political authority. This is in some respect the flip side of the enabling factors stated above, namely a locally relevant framing of food waste prevention and parallel initiatives on other governmental levels. Particularly regulation targeting the private sector, quantitative reduction goals, the removal of harmful policies or an overall economic shift towards sufficiency are areas of food waste prevention that go beyond solely local authority. This shift of responsibility away from municipalities expressed by respondents confirms that substantial policy change on the European, federal and state level is necessary not only to substantially reduce food waste, but also to create conditions enabling food waste prevention activities in local authorities in Germany.

4. Conclusions

4.1. Concluding remarks

Food waste is so far neglected in the literature that studies local environmental policymaking. By examining the dynamics impacting the agenda status of food waste prevention in local authorities, this paper adds important elements to the discussion about the necessary multi-level action to reach SDG 12.3 by 2030. According to our findings, whether further food waste prevention measures rise or falter on their way up the local agenda will not only depend on their technical feasibility, acceptability or expected costs. The aim of preventing food waste as embodied in such measures also needs to be attached to a problem category prominent at a given time, such as a recognised lack of food education. The skill of well-connected policy entrepreneurs to see such opportunities and stay persistent in bringing up food waste prevention in various contexts is a key enabling factor, particularly for measures that span across municipal departments. Equally of importance is the perceived acceptance and interest for food waste prevention among the public, as well as a direct or indirect connection to food waste prevention actors and initiatives at higher governmental levels. Here, the individuals' ability to take actions in local governmental structures when an opportunity window opens is a relevant success factor for policy change.

Building on these findings and in line with our theoretical approach we conclude with the following observations on the agenda success of municipal food waste prevention:

- The agenda success of municipal food waste prevention measures strongly depends on a persistent policy entrepreneur.
- The framing of food waste is more important for the rise of food waste prevention on the local agenda than evidence about the scale of the problem.
- Parallel enabling dynamics on other governmental levels are an important factor for the rise of local food waste prevention on local agendas.
- Strong interest groups that strategically frame municipal food waste prevention make local agenda change more likely.

4.2. Directions for further research

Finally, we identify three areas of research to close important gaps in this so-far underresearched field. For one, it is likely that the municipal level will more clearly demonstrate a conflict between the prevention and the better management of food waste. Public waste authorities may substantially contribute to food waste prevention in the future, but at the same time waste management providers as well as other local actors have vested interests that tend to conflict with the prevention of waste. Studies of this dynamic playing out in municipal waste management
— for instance based on the concepts of path dependency or advocacy coalitions — can give important insights on the challenges towards the better prevention of food waste overall.

Secondly, the impact of food councils on the rise of food waste prevention on the municipal agenda is of interest. The growing number of food councils is important for giving prominence to the field of urban food policy overall. Yet, our findings suggest that when it comes to local agenda setting, a synergy between food waste prevention and other food policy priorities such as regional, healthy, fair, or affordable food, is not a given. Therefore, through which dynamics food waste prevention is included or excluded from urban food policy agendas should be examined.

Lastly, more knowledge on the enumerated options and the effectiveness of local food waste prevention policies is needed. Based on interdisciplinary approaches, food waste streams and waste quantities at points under municipal influence should be assessed, as well as the potential to integrate food waste prevention in other municipal policies and concepts. The development of four urban food waste prevention indicators by the Milan Urban Food Policy Pact and FAO is a welcomed, but also only one of many steps needed in this direction.

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Assessing the potential for food waste prevention in the commercial food sector in Ireland

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Abstract

Food waste poses a significant environmental, economic and social problem, worldwide. In EU countries, the commercial sector (i.e. food retail and food service) accounts for an estimated 17% of total food waste and has been identified as the part of the food system with some of the greatest potential for food waste reduction. This research was carried out to address the lack of qualitative and sectoral-based information on commercial food waste in Ireland. First, sectoral estimates of total food waste were generated using existing national waste statistics. The Irish commercial sector generates an estimated 200,000 tonnes of food waste per annum. Of this, hotels, food retail, restaurants (both full- and quick-service) and workplace canteens were identified as the leading sources. Once identified, detailed qualitative and quantitative data on food waste within these sectors were gathered. Primary data collection was through on-site waste composition analyses, involving the separation, grouping and weighing of food waste. Within the food service sectors (hotels, restaurants and canteens) food waste was grouped according to food type (including unavoidable), waste type (e.g. preparation waste, unserved food, plate waste) and serving method. Within food retail, food waste was categorised according to food type and source location. These data were used to generate sector-specific food waste benchmarks and profiles. The results show that there is large variation in the level of food waste generated by different sub-sectors within food service. For hotels, a mean of 0.383 kg of food is wasted per cover (person served). This value is lower for full-service (0.263 kg) and quick service restaurants (0.146) and is the least for workplace canteens (0.079 kg). While some of this waste in unavoidable, much of it has the potential to be avoided. The mean levels of avoidable food waste vary from a high of 85% in the workplace canteen sector to a low of 62% in full-service restaurants. Food retail stores were categorised based on the presence or absence of prepared/heated food counters e.g. salad bars. Fruit and vegetables were found to be the leading source of food waste in food retail businesses. These foods made up an average of 34% of food waste in businesses that prepared/cooked food on site and 40% of food waste in stores that did not. Where food was prepared/cooked, food waste rates were, on average, 23 $kg/m_2/year$ compared with 19 $kg/m_2/year$ in retail businesses without this offering. The results from this research have substantially added to the understanding of food waste patterns in Irish commercial businesses. Both the waste profiles and benchmarks are relevant for businesses, sectoral organisations and policy makers alike. The detailed information gathered can be used to further understand the reasons behind food waste in Irish businesses while the overall trends identified will help inform future food waste prevention programmes and initiatives.

Keywords: Food Waste, Waste Composition Analysis, Waste Prevention, Food Service, Food Retail

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1. Introduction

Estimates of international food waste vary (WRAP, 2008; EC, 2010; Kummu *et al.*, 2012) but a commonly-used figure is that one third of all food produced for human consumption is wasted, or 1.3 billion tonnes globally (Gustavsson *et al.*, 2011). This level of waste represents a major environmental issue. Food waste includes the wastage of all of the associated resources that are required to produce that food. For example, globally each year,
1.4 billion hectares of land is used to produce food that is then lost or wasted (FAO, 2012). This waste is also responsible for significant levels of carbon emissions. Current estimates attribute 8% of global emissions to food loss and waste and reducing food waste has been identified as one of the best currently available actions to mitigate climate change (FAO, 2015; Hawkins, 2017). The importance of food waste prevention is recognised in the United Nations Sustainable Development Goals. Goal 12 includes a food waste specific target (12.3) that calls for a 50% reduction of food waste per capita at the retail and consumer level (UN General Assembly, 2015).

In Ireland, is estimated that 1 million tonne of food waste is generated annually (EPA, 2019). This includes food wasted from processing, distribution, commerce and household consumption. It excludes farm-level food losses and fishing discards, on which there is almost no published information.

Across Europe, the commercial sector (wholesale, retail and food service) accounts for approximately 17% of all food waste (including losses from food production) (Stenmarck *et al.*, 2016). At this level of waste generation, Ireland's commercial food sector would be estimated to produce 170,000 tonnes of food waste per year (Stenmarck *et al.*, 2016; EPA, 2019).

The food service sector contributes approximately 12% of total food waste in Europe (Stenmarck *et al.*, 2016). Food waste in service businesses occurs at several stages of business operations and the specific reasons for food waste in this sector are varied. They range from high-level factors like societal expectations to specific drivers such as the level of skill of employees (Heikkilä *et al.*, 2016). In Ireland, food service is growing steadily (Bord Bia, 2018). With more and more food being consumed outside of the home, there is an urgent need to improve the efficiency of this sector and prevent waste from increasing. Of course, reducing food waste is not just good for the environment. Research published in 2017 found that 99% of companies that undertook food waste prevention experienced a positive return on investment, with an average return rate of 14:1 (Hansen and Mitchell, 2017).

The food retail sector is directly responsible for a much smaller proportion of food waste in developed countries, at approximately 5% of the total (Gustavsson *et al.*, 2011; Stenmarck *et al.*, 2016). However, despite the relatively low level of waste produced directly by the sector, food retailers occupy a critical point in the food system and have influence up and down the chain. For example, a study carried out by the University of Edinburgh found that one third of farm produce is lost due to cosmetic standards maintained by the wholesale and retail sectors (Porter *et al.*, 2018). Shopping habits have also been found to be one of the most important influencers of consumer food waste, which accounts for over half of all food waste in Europe (Stefan *et al.*, 2013; Stancu *et al.*, 2016; Porter *et al.*, 2018). This influence over the rest of the food system makes the food retail sector a necessary point of focus in the effort to reduce food waste.

Unlike developing countries, were food is primarily wasted due to insufficient technology and infrastructure early in the food system, food waste in developed countries is most prevalent in later stages of the food system i.e. retail and consumption. This is due to the over-production and supply of food, relative to demand. Abundance and the low cost of food compared with the average income means that people in developed countries can afford to waste food (Gustavsson *et al.*, 2011). In fact, in many businesses' cases, it is cheaper to waste food than to invest in what is required to prevent it (Segrè *et al.*, 2014). In developed countries, the commercial sector (e.g. food retail and food service) has been identified as the part of the food system with the greatest possibility for food waste reduction (Parfitt *et al.*, 2010).

Food waste prevention is a priority area across the waste prevention policies of EU member states (O'Leary *et al.*, 2017). The United Nations Environment Programme (UNEP) has stated that the quantities and sources of food waste, and the reasons that it occurs, must be better understood so that future prevention initiatives can be successful (Herszenhorn *et al.*, 2014). Before food waste can be prevented, it must be clearly and accurately measured.

The aim of this study was to address the lack of detailed information on food waste in commercial businesses in Ireland. This was done through the identification of significant food waste-generating commercial sectors in Ireland; investigation into the quantity, character and sources of food waste in these sectors; and the development of sectoral food waste benchmarks. Not only does this work improve the overall estimates of national food waste, it also provides fine-level detail on the types of food wasted and the reasons for that waste.

2. Methodology

In order to effectively evaluate and compare national food waste data, there is a need for the harmonisation of food waste measurement and reporting methodologies (Tostivint et al., 2016). Therefore, prior to on-site analysis work, a best practice review of international food waste quantification methodologies was carried out. Two relevant international standards were identified - FUSIONS Food Waste Quantification Manual (Tostivint *et al*., 2016) and the Food Loss and Waste Accounting and Reporting Standard (FLW Standard) (FLW Protocol, 2015). The requirements of both of these methodologies are met by this food waste quantification methodology. Primary data collection was carried out through waste composition analyses from within commercial food businesses.

2.1. Sectoral Identification

For the purposes of this research, the Irish commercial food sector was broken down according to the sub-sectors estimated to produce the largest quantities of food waste. As no detailed, national-level data on food waste was available, these were identified through a desktop study examining existing national waste statistics. The primary sources of data used were the most recent EPA National Waste Report (EPA, 2014) and the EPA Municipal Waste Characterisation Report, 2008 (EPA, 2009). While the 2008 characterisation study examined all wastes, relevant food waste information was extracted from the raw data. Full details of this study are given in Broderick & Gibson, 2019.

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Estimates of the total food waste produced in Ireland were generated using two methods. Based on the total waste reported in the National Waste Report, the first method estimated the volume of waste generated by each sector.

Then, using the sectoral waste profiles from Waste Characterisation 2008, volumes of food waste were estimated. The second method applied sector-specific food waste generation factors, extracted from the 2008 Municipal Waste Characterisation raw data (EPA, 2009 Appendix F) to known sectoral metrics (e.g. employee numbers, national hotel bed nights) from the Central Statistics Office or state/representative industry bodies (Broderick & Gibson, 2019 and references therein). Both methods classified sectors according to NACE (Nomenclature of Economic Activities – the European statistical classification of economic activities). The results of the two method were compared. To account for the variation between the two estimation methods, the mean food waste value was calculated for each NACE sector. Based on a Pareto analysis of these sectoral data, the largest food waste producing sectors were identified for inclusion in this research.

While NACE classification of sectors was suited to the desktop review, and the identification of generic commercial sectors, it does not reflect typical convention within those sectors. Consequently, to align more closely with industry norms, businesses were broadly classified as being either food service or food retail for the remainder of the study. Further sub-classification of these sectors is outlined in the results.

2.2. Sampling Strategy

Waste composition analyses were carried out in 45 Irish commercial food businesses during the period of June 2016 – Sep 2018. The sampling strategy used was a non-probability based, quota sampling known as convenience sampling, whereby businesses were offered the assessment and could opt-in. In order to reduce the potential for sampling bias, businesses were recruited through a variety of channels, with a wide geographical spread. Efforts were made to cover a variety of business types, sizes, market segment, etc. In addition, the assessments were carried out during both week-days and weekends to address the variability within the 7-day working week. The sectoral investigations took place throughout a 2-year period, thus taking into account seasonal variability. The scope of the assessments included all edible food (i.e. avoidable food waste) and associated inedible parts (i.e. unavoidable food waste) disposed of over a full day of operation in each business.

2.3 Waste Composition Analysis Methodology

The on-site methodology employed in food service was based on that developed for food waste quantification in the Irish healthcare sector (CTC, 2014). This method was updated to comply with international best-practice (FLW Protocol, 2015; Tostivint *et al*., 2016). The food retail methodology was designed for this research, in-line with said best-practice standards.

2.3.1. Food Service

Food waste from thirty-five food service businesses was assessed. Food waste was captured as it occurred at source, before disposal, and was almost exclusively unpackaged. This ensured accurate results as food waste segregated post-disposal cannot always be identified with confidence. Each food service assessment lasted one full working day. Depending on business operations, this ranged from 8 to 16 hours. The composition of food waste in food service was categorised according to i) food type, ii) serving style (where relevant) and iii) waste source: preparation waste, plate waste, unserved food waste, and residual waste. These waste sources are described in Table 1.

Table 1. *Waste type (or source type) categorisation for food service assessments*

Food Waste Type	Description	Examples
Preparation	Any food material that was **not intended for consumption.**	Vegetable/fruit peelings Meat trimmings/bones Oils/fats Coffee grinds
Plate Waste	Any food that was **served but uneaten.**	Food from individuals' plates Bread baskets and milk jugs from table Dishes of vegetables/potatoes from tab
Unserved Food	Food that was **intended for consumption** but did not leave the kitchen/serving area.	Food from bain-maries/serving trays/displays/waiter trays Food from the kitchen that was intende for consumption Unused ingredients or unserved leftove
Residual Food	Food waste derived from plate/pot washing. Often scraped/washed from ware or emptied from trap in sink.	Contains a mixture of prepared, unserv and plate waste Can have a high water-content May not always be present

There were 16 categories of food type applied: bread, cereals, chips (French fries), dairy (excluding milk), dessert, eggs, fish, meat, milk, potatoes, salad, sauce, soup, vegetables, unavoidable. Milk was the only drink included - water, tea, coffee, soft drinks and alcohol were all excluded.

The unavoidable food waste category was included for the food service sector only. It was classified based on what foods are commonly considered as 'unsuitable for human consumption' within this industry. Examples include vegetable peelings, fish skins, animal bones, leftovers from the production of stock and sauces. There are of course cultural variations to the types of food waste considered to be unavoidable. For this work, the cultural norms of Irish food service businesses were broadly applied.

The results of the waste compositional analyses were compared with a measure of activity within each business to create a benchmark value. The measure used was the number of people served, or 'cover'. This is a metric that is widely available and understood across the food service industry.

2.4 Food Retail

In the food retail sector, 10 food waste assessments were carried out. Due to lack of access in retail businesses to food waste pre-disposal (as in food service), food waste was measured post-disposal but pre-collection i.e. from within on-site waste bins. Assessments were arranged around the existing waste collection schedule to maximise the amount of food waste available for study. An international food characterisation system, The Codex General Standard for Food Additives (GSFA), recommended by the FLW Protocol, was applied in the food retail sector (FAO & WHO, 2017). This characterisation includes drinks, other than water.

Unlike in food service, food waste was not classed as avoidable or unavoidable in this sector. It was not

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possible to gather this information without making assumptions about the waste. For example, food found with damaged packaging in the waste bin may have been discarded because of the damaged packaging or it may have been

discarded for a different reason with the damage to packaging occurring after disposal. In terms of source location, seven areas were considered: ambient (non-chilled shelves), bakery, butcher, chilled, deli, frozen, and fruit & vegetables. Food waste from salad bars and other self-service areas for prepared food were included in the deli category.

Where present, estimates of packaging weights were deducted from the results. This was primarily based on data from a previous study which reported the weight of packaging as a percentage of the weight of food items, by food category (Lebersorger and Schneider, 2011). Not all food categories encountered in this study were directly represented in the Austrian results. Consequently, a small-scale assessment of relative packaging weights was carried out to supplement the available data-set.

Food retail surveys were carried out in one day, typically 7 – 8 hours. In order to generate benchmarks, food waste results were scaled up for one year and compared to store size (in m^2). Store size refers to external area of the building and is a common factor used when benchmarking the retail/food retail sector (e.g. kWh/m^2/year is used for energy). The areas used in these calculations were estimated to the nearest 100 m^2 using Google Maps, satellite view and 'measure distance' tool.

3 Results and Discussion

3.2 Sectoral Food Waste

This study identified accommodation (i.e. hotels), food retail, restaurants and offices (i.e. workplace canteens) as the four leading sectors for food waste generation in Ireland (Figure 1). Three of these NACE sectors can be grouped more generally under the heading of food service (accommodation, restaurants and workplace canteens). These sectors account for an estimated 100,000 tonnes of food waste per annum. Food retail is estimated to produce 45,000 tonnes of food waste per annum.

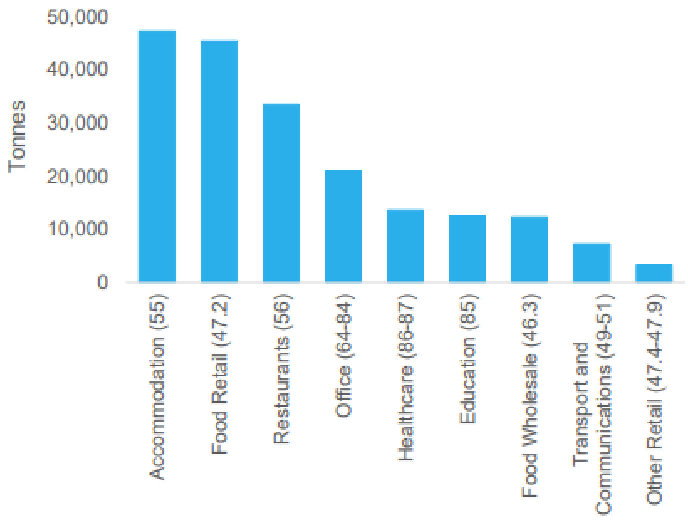

Figure 1. Estimated commercial food waste in Ireland by NACE sector (2016)

3.3 Characteristics of sectors chosen for study

For the purpose of the on-site waste composition analyses, hotels were taken to represent the accommodation sector. Hotels dominate the accommodation sector in Ireland accounting for 76% of occupied bed-nights in 2015 (Fáilte Ireland, 2015; IHF, 2015). In addition, other accommodation types typically only serve breakfast, and limit food service to those staying in the facility, thus serving much less food overall. In some cases, the results from the hotel sector were split based on the serving situation i.e. made-to-order and pre-prepared for buffet or event.

Restaurants were classified as either full-service or quick-service. Full-service restaurants are those that offer table service and prepare most food as it is ordered (made-to-order). The businesses included in this study were either bistro or bar restaurant styles. Quick-service restaurants (also known as limited-service restaurants) consist of both traditional fast-food outlets and fast-casual restaurants (see Section 2.4.1 for details). Traditional fast-food or takeaway outlets were excluded from this study. In such businesses, a large number of the meals served are taken away from the premises and those that are served on-site are disposed of by the customer in general waste bins in the dining area (as opposed to going back to a central wash-up area).

Workplace canteens are commonplace throughout Ireland and are in both public institutions (e.g. county councils) and private companies. They range in size (serving anywhere between 50 to 1,000 people) and services provided (variety of meal options, salad bar, etc.). In general, the number of people to be served is known in advance, though of course there are daily fluctuations due to the dynamics of working life.

Food retail businesses were classified based on the presence of ready-to eat offering, known as ‘serve-over’. Serve-over is an industry term for this type of product, served to customers, over a counter. It does not include in- store bakeries. This form of food retail is very common in Ireland. Some supermarkets and many smallconvenience stores offer a range of hot and cold deli foods and made to order sandwiches. In some cases, it also includes salad bars, fresh meat from a butcher counter and ready-made hot meals. Offering serve-over food means that retailers are involved in cooking and preparation of food, ready for direct consumption. This is a much different practice to conventional retail, where products are bought, stored and sold, with no preparationrequired on-site.

With this context. Figure 2 shows the various stages in food service and food retail businesses where food waste can occur.

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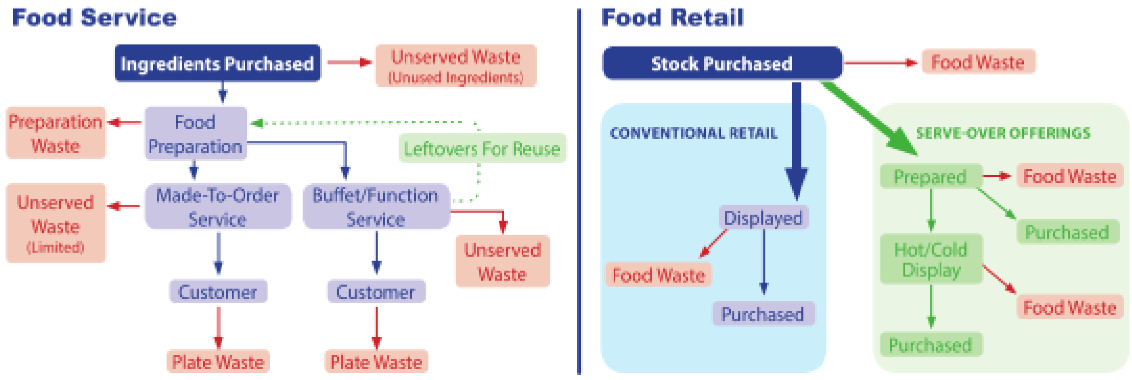

Figure 2. Flow chart of locations of potential food waste occurrences in food service and food retail operations

3.4 Food Service

Waste composition analyses were carried in hotels, full-service restaurants, quick-service restaurants and workplace canteens. The level of food waste varied among the sub-sectors of food service studied (Figure 3). When compared to the number of relevant covers, hotels have the highest mean food waste level at 0.383 kg/cover. Workplace canteens have the lowest level of food waste at a mean value of 0.079 kg/cover. The absolute levels of food waste recorded during the day long assessments varied from just 7.85 kg in a workplace canteen to 228 kg in a large hotel.

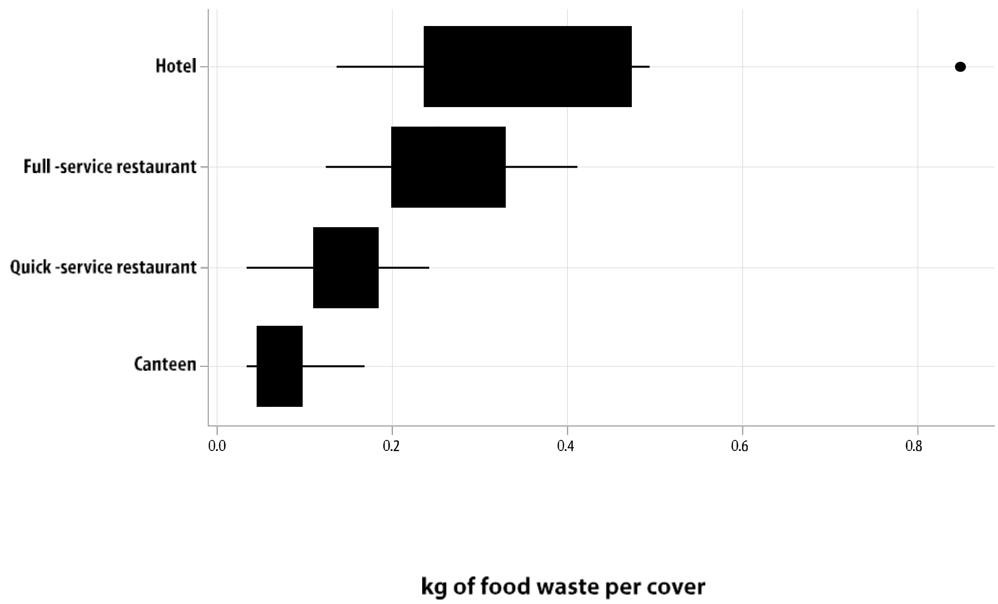

Figure 3. Boxplot of sectoral food waste benchmarks

Figure 4 provides the detailed food waste composition results for the four sub-sectors included in this study. Further detail is given in Table 2. Although the composition of food waste varies between each sub-sector, some trends can be seen.

On average, vegetables are the most commonly wasted food type (11%), followed by bread (9%), meat (8%) and potatoes (7%). These are some of the foods that are most commonly served in Irish food businesses. Vegetables, potatoes and meat are also the foods that are typically associated with main meals. With this in mind it is understandable that these are the largest contributing food types to food service waste. Sauce is the next most commonly wasted food type, and this was across all sub-sectors. This waste was typically as a result of the over- serving of sauce with meals (e.g. in ramekins, gravy boats, etc.). On a cost per kg basis, sauce is relatively expensive compared to other foods and, as such, represents an excellent opportunity for waste reduction and cost savings.

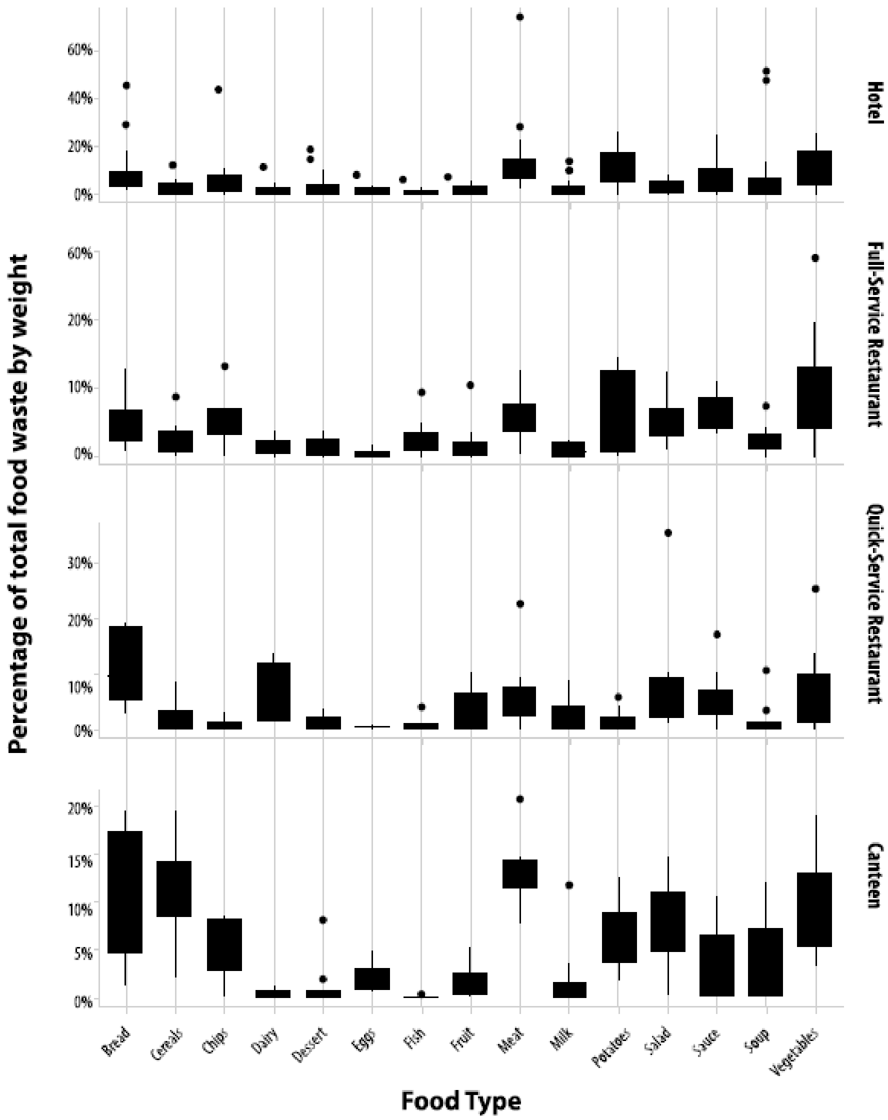

Figure 4. Boxplots of composition of avoidable food waste in food service businesses

Although not the leading source of waste, meat should also be an area of focus due to its financial and environmental costs, having the largest carbon footprint per kg of all food types, as well as usually being the most significant user of land and water resources per kg of food (Clune *et al*., 2017 and references therein).

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Dairy, eggs, fish and fruit make up approximately 2% or less of total food waste in all sectors. Desserts and milk are similarly low for every sector other than quick-service restaurants, where they make up 6.5% and 4.5% of food waste respectively. The provision of milk jugs on tables and the high proportion of dessert sales to main meals in cafes is a possible cause of this trend. Cereal waste is a much larger component of food waste in canteens (13%) than any other sector (approximately 3%). This is likely influenced by large quantities of unserved porridge, common in workplace canteens. A similar occurrence is observed for potato waste in hotels (11% in hotels versus 3-7% on other sectors).

Table 2. Characterisation of food waste from food service businesses

			Food Waste per cover		Source			Food Type %															
	n	Mean Food Waste (kg)	Mean kg/cover	SD		Mean %	SD	Bread	Cereals	Chips	Dairy*	Dessert	Eggs	Fish	Fruit	Meat	Milk	Potatoes	Salad	Sauce	Soup	Vegetables	Unavoidable
Hotel	11	90	0.38	0.21	Preparation	28	15	6.4	2.8	4	0.9	1.7	0.9	1.1	1.3	8.4	1.3	12.5	3.4	7.5	3.1	12.1	32.5
					Plate	37	15																
					Unserved	32	20																
					Residual	2	5																
Full-service Restaurant	8	28	0.26	0.09	Plate	37	23	5.8	3.7	6.4	1.6	1.4	0.5	2.2	2.3	6.2	1.1	6.5	4.6	6.7	2.5	10.2	38.3
					Preparation	46	17																
					Unserved	16	11																
					Residual	1	2																
Quick-service Restaurant	8	32	0.15	0.07	Plate	46	26	11.3	3.0	3.5	1.0	6.5	1.4	0.3	0.7	5.4	4.6	3.4	6.0	4.5	3.6	8	36.7
					Preparation	27	24																
					Unserved	25	11																
					Residual	2	2																
Canteen	9	48	0.08	0.05	Plate	18	8	10.1	13.3	4.1	0.4	0.9	1.9	0	2.1	11.6	0.9	7.5	7.3	6	5.6	13.5	14.8
					Preparation	39	18																
					Unserved	43	18																
					Residual	0	0																

The sources of food waste vary between all of the sub-sectors studied (see Figure 5) and can give a broad indication of the reason for such food waste generation. In hotels, plate waste is proportionally the largest source of food waste (41% of total food waste). This indicates that portion-size may be a leading factor in the level of waste in this sector. In full-service and quick-service restaurants, preparation waste is the leading source (44% and 45% respectively), while it is just 19% in workplace canteens. A likely influencer of this is the extent to which ingredients are purchased pre-prepared. In canteens, this is a common practice, particularly for potatoes and vegetables. This practice also contributes to the fact that preparation waste is lower than any other sector studied and directly relates to the low overall level of unavoidable waste in canteens.

Unserved food waste is highest in canteens (40% of total). Workplace canteens typically batch cook food to serve large numbers of people in a short amount of time. All of the canteens assessed prepared food ahead of time and served it directly to customers, from menus, who queue for counter service (as opposed to table service in restaurants). Although this method creates good potential for communication between staff and customers, potentially influencing plate waste, it poses a real challenge in terms of the over-preparation of food (which can become unserved food waste if unused).

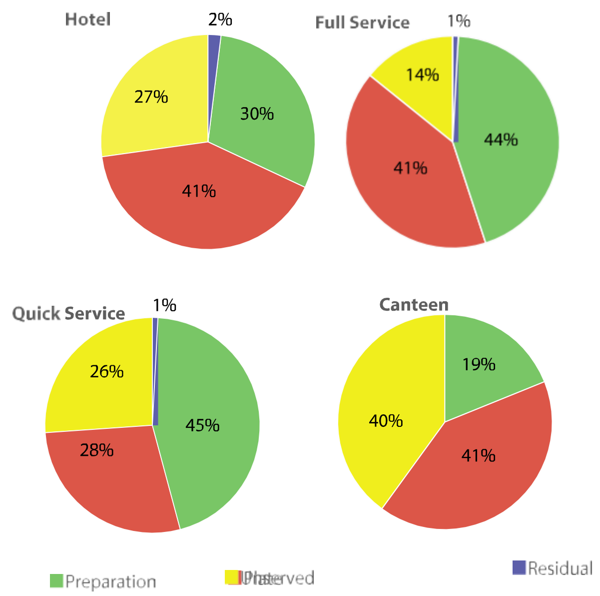

Figure 5. Mean food waste profile by source for food service

The higher levels of unserved food waste in quick-service restaurants (26%) compared to full-service restaurants (14%) is likely influenced by both serving style and types of food served. Similar to canteens, it is common for food to be pre-prepared in quick-service restaurants, and on display for customers to choose. This is typically not the case in full-service restaurants.

3.3.1. Avoidable Food Waste in Food Service

Figure 6 shows that the results for avoidable and unavoidable food waste in full-service (62:38) and quick-service restaurants (63:37) are very similar. Hotel daily service (mostly made-to-order) only deviates slightly from this (66:34), while hotel functions (pre-prepared) have a completely different profile (87:13). Canteens have similar levels of avoidable waste as hotel functions (85:15). Some of the variation in these results could be attributed to different levels of in-house food preparation among the sub-sectors. For example, as noted previously, workplace canteens typically purchase a higher proportion of pre-prepared ingredients than full-service restaurants.

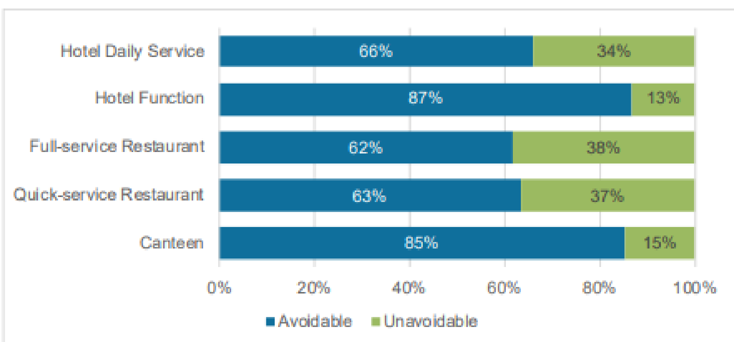

Figure 6. Breakdown of avoidable and unavoidable food waste in food service

Several previous studies across Europe have looked at food waste in service and found similar level of

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avoidable and unavoidable waste. Workplace canteen food waste has previously been found to be 71% avoidable (Betz *et al.,* 2015) while canteens in the education sector, were found to be 77% avoidable in the UK and 92% in Switzerland (Cordingley *et al.,* 2011; Betz *et al.,* 2015) Beretta *et al.*, 2013 compiled the results of several earlier studies and calculated an average food waste composition of 60% avoidable food waste. An extensive review by FUSIONS which gathered existing data on food waste in the EU-28 estimated that avoidable food waste makes up 59% of food waste from food service (Stenmarck *et al.*, 2016).

3.3.2. Effects of serving style on food waste: a focus on hotels

The effect of serving style on food waste was examined within hotels. In many Irish hotels, the serving style of food varies depending on the time of day or service type. Food is often pre-prepared for events and functions, while is made to order in the bar or restaurant. In addition, the number of diners is often known in advance for events and functions and this can make predicting food requirements easier. However, this style of service also requires large amounts of food to be available at once. Unlike made-to-order service this means that, at the cooking stage, assumptions or predictions must be made to ensure enough food is prepared.

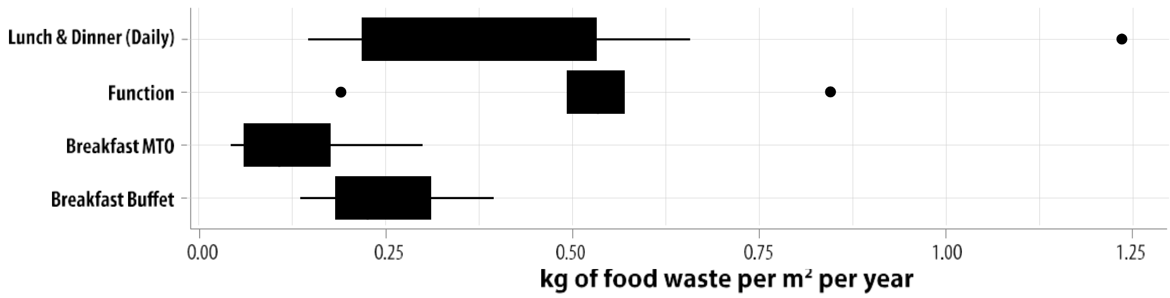

Figure 7. Food waste benchmark for varying styles of service in hotels

Figure 7 shows the variation in the food waste per cover value for different forms of service within the 10 hotels studied. The effects of serving style on food waste levels can be seen across meals. Made-to-order (MTO) breakfasts generate the lower levels of food waste (mean of 0.134 kg/cover) compared with buffet breakfast (mean of 0.251 kg/cover). The same trend is apparent when comparing lunch and dinner daily-service (0.364 kg/cover), which is primarily made-to-order, with functions (0.527 kg/cover) where food is pre-prepared. Other studies examining food waste in hotels similarly found that serving style influenced food waste, with à la carte serving resulting in less waste than buffet (Silvennoinen *et al.*, 2015; Pirani and Arafat, 2016)

Compared to the other food service sub-sectors, hotels have a number of unique challenges when it comes to food waste prevention. The emphasis on luxury, comfort and customer care can make waste prevention activities appear contrary to the core service of a hotel. Unlike other food businesses, food is just one part of the service offered by hotels. Food waste is often seen as an acceptable cost to the provision of a high-quality customer service. Consequently, actions to prevent food waste are perceived as a potential risk to customer experience. This observation was particularly apparent during wedding functions. Despite the number of diners being well established in advance, the level of unserved waste in these instances was notably high (mean of 32% or 0.230

kg

per cover). The risk to customer satisfaction and reputation is perceived to far outweigh the cost incurred by this level of overproduction. Any potential food waste prevention activities must take this into account.

3.5 Food retail

Based on mean values, food waste generation for food retail businesses in Ireland is estimated to be 19 kg/m2/year for conventional retail businesses, without serve-over offerings. Retail business with serve-over offerings were found to waste an estimated 23 kg/m2/year (Figure 8).

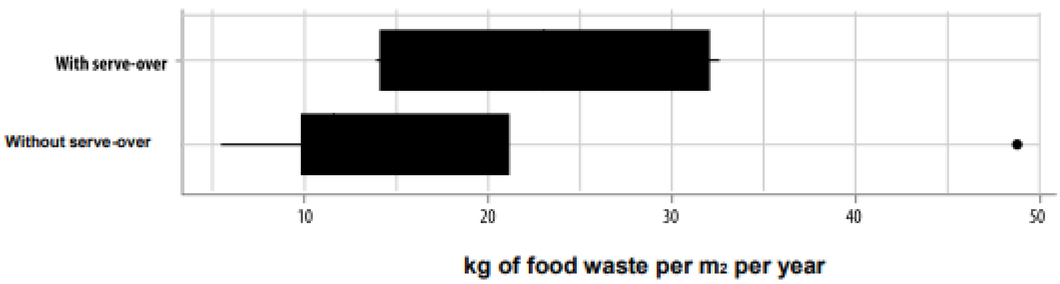

Figure 8. Boxplot of food waste benchmark for food retail with and without serve-over

The characterisation results are depicted in Figure 9 with full details provided in Table 3.

The character of food waste varies between retailer businesses with and without serve-over. In conventional retail, without serve-over, vegetables (21%), fruit (15%), bread and fine bakery (14%), dairy (14%) and meat (12%) were found to be the leading sources of food waste by mean weight. For businesses that offer serve-over foods, vegetables and fruit were still the leading sources, at 19% and 25% respectively. Bread (15%) and prepared food (14%) were also major components.

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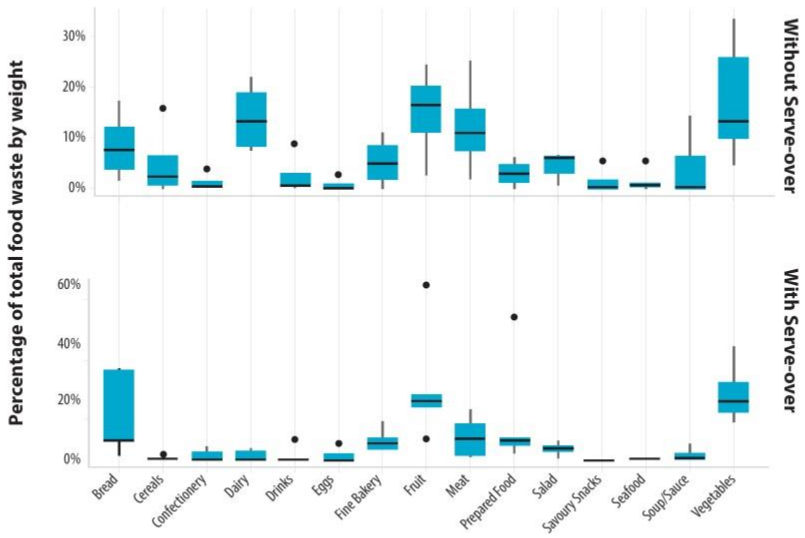

Figure 9. Boxplots of composition of food waste in food retail businesses

The food retail methodology, which entails waste composition analysis post-disposal, is not conducive with the accurate characterisation of food waste from serve-over. Similar to food service, once disposed of this type of waste amalgamates and becomes extremely difficult to characterise. In addition, without analysing waste at this stage does not allow for the identification of the source type. As a result, serve-over wastes could only be segregated into broad categories (e.g. deli counter versus butcher counter).

Table 3. Characterisation of food waste from food retail businesses

			Food Waste Generation (per m²/year)		Source			Food Type (%)														
	n	Mean Sample Size (kg)	Mean %	SD (of %)		Mean %	SD (of %)	Bread	Cereals	Confect-ionary	Dairy	Drinks	Eggs	Fine Bakery	Fruit	Meat	Prepared Food	Salad	Savoury Snacks	Seafood	Soup/ Sauce	Vegetables
Stores with serve-over	5	252	23.08	10.49	Ambient	6.3	3.9	15.0	0.5	1.6	1.5	1.5	1.5	6.1	24.9	7.7	13.7	4.2	0.0	0.3	2.6	18.8
					Bakery	21.3	31.1															
					Butcher	4.5	7.6															
					Chilled	14.4	6.9															
					Deli	19.7	20.2															
					Frozen	0.1	0.4															
					Fruit & Veg	33.8	21.1															
Stores without serve-over	4	141	19.23	19.84	Ambient	20.9	5.3	8.5	5.1	1.4	14.0	2.7	0.8	5.2	15.0	12.2	3.0	4.0	1.8	2.0	3.7	20.6
					Bakery	7.3	4.8															
					Butcher	0.0	0.0															
					Chilled	31.0	22.3															
					Deli	0.0	13.6															
					Frozen	0.9	1.0															
					Fruit & Veg	40.0	53.0															

When analysed by source, the 'fruit and veg' or fresh produce section of stores was the leading source of food waste for both types of retail businesses assessed (Figure 10). Fruit and veg accounted for 34% of waste for stores with serve-over and 40% for those without. After fruit and veg, chilled is the next largest source for stores without serve-over (31%). Bakery is the second largest source in stores with serve-over (21%).

These results are in line with those published by one of the major retailers in the Irish market. Fruit and vegetables is the leading source of waste at 31%, followed by bakery (25%) and meat, fish and poultry (15%)

(Tesco Ireland, 2018).

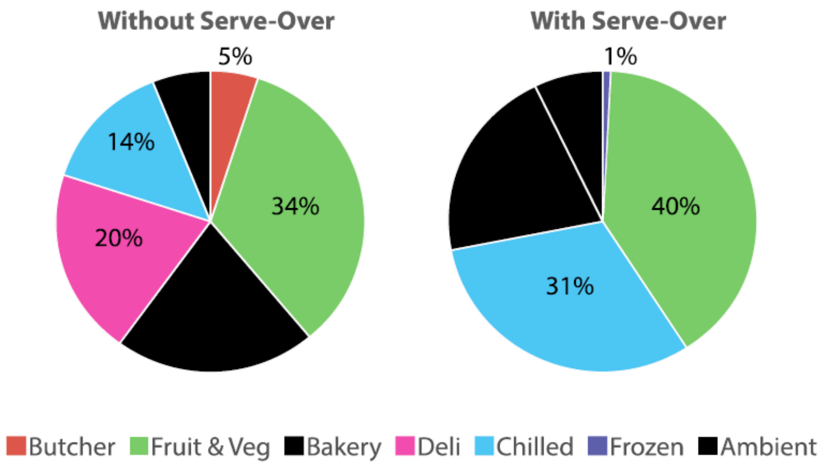

Figure 10. Mean food waste profile by source for food retail

Perishable foods were consistently found to be the largest components of food waste in retail. This aligns with the findings of previous studies on food waste in food retail, where products with the highest perishability are those that are most commonly wasted (Pekcan, 2006; WRAP, 2008).

The custom of 'serve-over' offering in Irish retail businesses appears to increase overall food waste. This may be due to the high perishability of prepared foods. It may also be linked to other factors such as the style of retail store or target customer base (i.e. upper market stores, which often have substantial serve-over offerings, may also carry a larger range of perishable breads and fruits). More work is needed to establish the characteristics of retail business that influence food waste levels.

3.6 Potential for Prevention

The level of avoidable waste across the food service sector indicates that there is excellent potential for food waste reduction. The waste characterisation results on avoidable and unavoidable food waste (see Figure 6) were applied to the estimates of total national food waste by sector to the hotel/accommodation, restaurant and workplace canteen sectors. This identified that there are an estimated 32,000 tonnes of avoidable food waste in the Irish hotel/accommodation sector, 25,000 tonnes in restaurants and a further 16,300 tonnes from workplace canteens. (Figure 11) This amounts to over 73,000 of potentially avoidable food waste annually in Ireland from these three sectors. Due to limitations in the food retail data, similar national estimates cannot be made for this sector.

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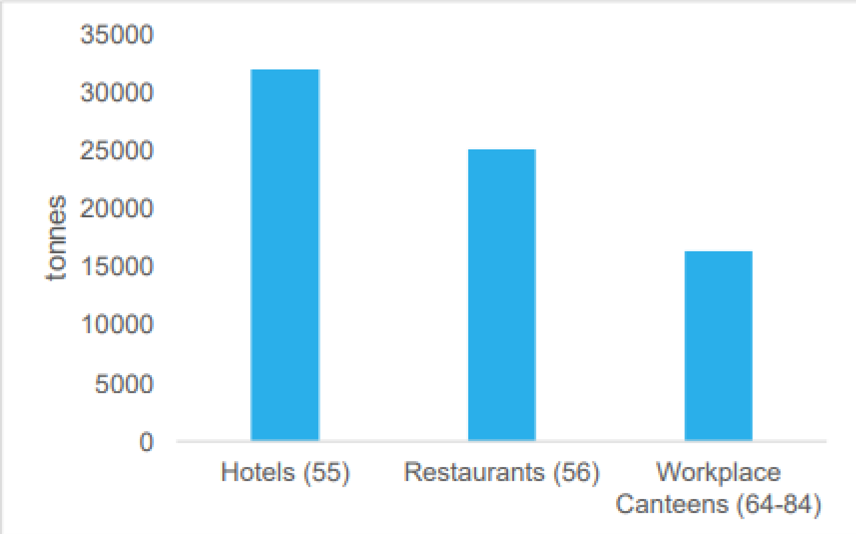

Figure 11. Potentially avoidable food waste in food service sector in Ireland

Additionally, it is worth noting the wide variation in the levels of food waste in businesses within the same sector. it is important to note that while these are average values, variations do occur. While the mean levels reported hear vary from 0.8 kg/cover in canteens to 0.38 kg/cover in hotels. The sample variation was greater. Many businesses assessed were operating at food waste levels far below the average. This demonstrates that current average food waste levels have the potential to be reduced.

3.7 Limitations of the study

Both the food service and food retail methodologies potentially under-record true food waste. The Hawthorne effect or 'observer effect' (Parsons, 1974) is an unfortunate consequence of the waste composition analysis method applied to food service. While it allows very accurate characterisation of food waste presented, the presence of the project team in the kitchen very likely influenced staff behaviour. In many cases there was understandable hesitancy from staff around the supplying of food waste to the team for measurement. This behaviour particularly affects the unserved food waste fraction. Where possible, the research team were kept out of sight of customers to prevent any potential effect on plate waste. However, in some cases this was not possible.

The food retail assessments examined waste in the segregated food waste stream, post disposal. This removes any potentially observer-based effects. However, the most recent EPA National Waste Characterisation Report indicated that there are substantial levels of food waste being disposed of in other waste streams. For example, residual waste from food retail is reported to include 42.2% food, while mixed dry recycling stream contains 16.5% food (EPA, 2018). This waste goes uncharacterised by the food retail methodology applied.

4 Conclusions

Food waste, particularly that which occurs at the latter end of the food system has a negative environmental impact due to the wasted resources used in its production, transport, and disposal. This research provides an estimate of the magnitude of commercial food waste in Ireland, as well as detailed data on its characterisation.

Based on the best available data, total food waste from the commercial sector in Ireland is estimated at approximately 200,000 tonnes per annum. The main sectors contributing to this food waste have been identified as food service (including hotels, restaurants and workplace canteens) and food retail. These sectors account for approximately 52% and 23% of the estimated national commercial food waste, respectively. Within food service, the level of waste generation varies between sub-sector. Hotels produce the highest level of food waste per person served while work-place canteens have the highest level of avoidable food waste.

Between 62% and 87% of food wasted in food service is potentially avoidable amounting to an estimated 73,000 tonnes in the sectors studied. The level of avoidable waste is influenced by both the business type and serving style.

In food retail, vegetables and fruit are the leading sources of waste in businesses. Where present, prepared foods are also a major component of food waste in retail. The level of highly perishable products appears to influence food waste.

Acknowledgements

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Underlying sustainability in weblogs about food topics: Classification and evaluation of food-related Ewom generators

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Abstract

The present world has led consumers to become increasingly concerned about the environment. Such concerns have also begun to be displayed in their decisions and behaviours, with individuals increasingly interested in acquiring environmentally friendly products. Besides that, the arrival of the Internet has altered the traditional consumption patterns of individuals and the way in which they interacted and searched for information years ago. Nowadays, online platforms, generally known as web 2.0, are usual websites where consumers read reviews from other consumers before making a final decision. Considering both issues together, it has been observed that research on eWOM and sustainable consumption is on initial phases and needs more attention, for instance, by evaluating the interaction between eWOM and sustainable consumption on food products. Following this vein, the present study aims at determining the tone in the content of the food-related eWOM, and, if a sustainable food-related eWOM emerges as relevant, shaping its weight on the Internet. For that purpose, it was conducted a survey study with a total sample of 428 authors of food-related blogs/videoblogs. Afterwards, once executed a cluster analysis, three differentiated groups were highlighted, namely conservative savers, gourmets, and greens. Anyway, a subsequent ANOVA test considering the variables of cluster membership and centrality levels indicated that greens just as much as conservative savers and gourmets show the same power of influence on the Web 2.0. Taking all together, these results have revealed information of great importance that reflects in implications for businesses and professionals.

Keywords: Sustainable e WOM, Food Topics, Weblogs/video-Blogs, Cluster Analysis, Centrality Analysis

1. Introduction

There is no doubt that the arrival of the Internet has modified dramatically the way and rhythm of our lives, providing us as consumers with a range of advantages that offline channel does not. This circumstance reflects directly on our consumption patterns, which are today quite different from what they were only some years ago.

In this regard, the purchase behaviour represents a fair example as the online channel is becoming, for lots of consumers, the most common way of acquiring many product categories. According to data retrieved from Statista (2018a; 2018b), in 2017, 60.2% of global Internet users purchased products online, figure which is expected to grow to 63.0% in 2019. These percentages amount, in terms of sales, to 2.30 trillion U.S. dollars in 2017 and a projection of 2.84 trillion U.S. dollars in 2018 and 3.45 trillion in 2019, which confirms the growing trend.

Not solely that, but the Internet has also modified the traditional way in which individuals interact (King et al. 2014). A recent study (GWI, 2018) points that, worldwide, the typical Internet user spent at around 2:15 hours per day on online social networking in 2017, while it was 1:36 hours back in 2012 (GWI, 2016). The fact is that users have rapidly integrated this instrument (online social networking, also termed as electronic word-of-mouth, eWOM hereafter) into their decision-making processes (Zhu and Zhang, 2010) and, hence, their routine of search for information (Litvin et al., 2008).

Besides that, but definitely not less important, the present world has also led consumers to become increasingly concerned about the environment. Such concerns have begun to be displayed in their decisions and consumption patterns, with individuals increasingly interested in acquiring the so-called 'environmentally friendly products', tendency which has motivated the emergence of a 'new marketing philosophy', known as 'green marketing' (Belz and Peattie, 2009), whose aim is to achieve a balance between the objectives of sales and profits of companies and a concern for society and the environment (Kärnä et al., 2002).

In this sense, firms, seeking to remain competitive in the market and to achieve the fulfilment of consumer demands, have begun to incorporate these newly emerging worries in their management and marketing decisions by paying special attention to market segmentation and market orientation (do Paço et al., 2008; Lu et al., 2013; González et al., 2015).

Considering both issues together, it has been observed that research on eWOM and sustainable consumption is on initial phases and needs more attention in order to attract the empowerment of eWOM communications since, according to some authors, focusing on dissemination of efficient eWOM results in influence and impact on consumers behaviour (Fan and Miao, 2012; Reichelt et al., 2014). Likewise, few studies have evaluated the interaction between eWOM and sustainable consumption on food products. So for, the present study aims at determining the tone in the content of the food-related eWOM, and, if a sustainable food-related eWOM is identified, shaping its relevance on the Internet.

The paper is structured as follows. The next two sections review the essential literature related to eWOM, food aspects, and sustainability. After this contextualisation, the main methodological aspects related to the

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investigation are presented in the fourth section. Subsequently, the results are presented in the fifth section. Finally, the last section gathers some brief conclusions.

1.1. Ewom in the food context

Online weblogs/vlogs, discussion forums, opinion websites, social network platforms themselves,… are all websites consumers visit more often to read reviews from other consumers and/or to generate reviews for other consumers (Gruen et al., 2006; López and Sicilia, 2013; Luo et al., 2013; Serra and Salvi, 2014), tools that conform the termed Web 2.0, that is, the participative and interactive web emerged in about 2000 and created by and for users from collective intelligence (Boyd and Ellison, 2008; O'Reilly, 2005).

Following this line, as not all participants on Web 2.0 are truly active posters, it can be distinguished between passive consumers or opinion seekers and active consumers or opinion givers (Chatterjee, 2011; Chu and Kim, 2011; Flynn et al., 1996; Reynolds and Darden, 1971; Sun et al., 2006; Wang and Fesenmaier, 2004). Opinion seekers mainly focus on the search for information, devoting most of their time to read comments and experiences previously posted by other consumers. On the contrary, opinion givers are these consumers who share their opinions with other consumers, posting their judgments in diverse forums, platforms and websites.

Concretely, in the Spanish market (AIMC, 2018), it is worth stressing that 77.0% of online customers stated to read comments and reviews coming from other customers before making a final decision with 50.9% of them trusting largely those reviews. In addition, 58.8% of Spanish Internet users stated to have posted any kind of review about a product or service during 2017 (AIMC, 2018).

Marketing researchers have labelled this phenomenon with the broad appellation of electronic Word-of-Mouth. Continuing the line adopted by Hennig-Thurau et al. (2004, p. 39), eWOM can be defined as "*any positive or negative statement made by potential, actual, or former customers about a product or company, which is made available to a multitude of people and institutions via the Internet*".

The significance of eWOM lies in its considerable commercial impact due to its capacity to influence and to determine attitudes and behavior of consumers toward a product, service, brand or organization (Brown and Reingen, 1987; Christiansen and Tax, 2000; Nadeem et al., 2011; Solomon et al., 2006; Van Noort and Willemsen, 2012) even more so than the traditional mass media such as radio, press, and television. Therefore, it can be assumed that opinion givers are trusted by opinion seekers to provide useful advice, and considered for this reason the origin of eWOM (Jeong and Jang, 2011; Litvin et al., 2008).

The food sector, of course, is not apart from this scenario since food-related eWOM represents a well-settled practice. According to Nielsen (2014), 52% of Internet users performed roles as opinion seekers, carrying out online processes of search for information about recipes, gastronomy, nutritional details of products, reviews of restaurants, or consumption experiences with brands before making a final decision about a purchase. On the other hand, in terms of opinion giving, 32.3% of Internet customers generated, either positive or negative, online reviews about products, services, or food brands during 2014 (MAPAMA, 2015).

The performance of food-related eWOM is thus in the Spanish digital context, without any kind of doubt, a widely developed routine supported by a broader group of opinion givers who are actively present on social networks propelling the flow of information online, revolutionizing the relationship between consumers and brands, and contributing to increase the standards of demand. Clear evidence of this relevance are some annual awards such as 'Premios Bitácoras' (2016) or 'Premios Vlogger' (2017) where food/gastronomy/cuisine represents one of the remarkable categories.

1.2. Food products and sustainability

Debating on sustainability and food consumption, it is worth of mention that there is an old relation between them dating back to the 1980 (Rana et al., 2008), but it was in the 1990s when the market for sustainable products experienced a huge growth mainly due to the generalised consumer's concern about the ecological impact of their purchases (Schuhwerk and Lefkoff-Hagius, 1995).

Parallely, also during this period, several companies were found guilty of conscious advertising of false environmentally friendly attributes which resulted in a deep mistrust of consumers for the environmental efforts of many organizations (Zinkhan and Carlson, 1995). In this line, since then, governments have introduced different regulations and guidelines regarding the exploitation of environmental claims in an effort to prevent false advertisements and decrease consumer mistrust (Montague and Mukherjee, 2010).

Throughout this time, consumers' environmental concern, despite previous acts of companies' fraudulent behaviour, has not only not decreased (Montague and Mukherjee, 2010), but also still represents a profitable market segment (Smith and Brower, 2012). The fact is that, by introducing ecologically friendly products into the market, companies can assure that needs of environmentally conscious consumers are better addressed (Lu et al., 2013).

In particular, the food sector has to face two primary challenges in terms of sustainability accomplishment (Hartmann, 2011). First, the food sector is directly influenced by environmental, human and physical resources, and second, the complexity and mixture of its reality provides different perspectives of approaching that sustainability, which further implies conflicting perspectives in this respect. Costanigro et al. (2016) gather a series of nine activities regarded by consumers and geared to this accomplishment, which were the search of animal welfare, control of energy consumption, control of water consumption, control of air pollution, community involvement, encouragement of employee opportunities, stimulation of local operations, waste management, and commitment to sustainable agricultural practices. Moreover, to these actions it could be added the communication of sustainability-related information as a sustainable activity itself, understood as an exercise in transparency and reliability.

Anyway, targeting green consumers can be tremendously challenging for companies since, even if green consumers want products that will protect or benefit the environment, they will not purchase a product only for its environmentally friendly attributes (Vermillion and Peart, 2010; Grunert, 2011; Dzene and Yorulmaz, 2011). Likewise, research indicates that consumers will not sacrifice other product characteristics such as convenience, availability, price, quality and performance in place of eco-friendly characteristics (Ginsberg and Bloom 2004). In practice, this means that sustainable and non-sustainable products must be deemed equivalent in regards to these attributes in order for most consumers to even consider purchasing the sustainable product.

As evidenced of this latter, the research on sustainable consumer behaviour has also been inevitably reflected in a wide-ranging studies where the effects on consumers of sustainability criteria of products are examined as opposed to the effects of other sort of criteria such as customer loyalty, brand image, reputation and credibility (Cha et al., 2016; Choi, 2017; Obermiller et al., 2009; Pino et al., 2016; Pivato et al., 2008; Swimberghe and

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Wooldridge, 2014), product awareness and product evaluation (Costanigro et al., 2016; Kozup et al., 2003; Lee et al., 2014; Lotz et al., 2013), or purchase intention and willingness to pay –WTP- (Chen et al., 2016; Hartmann, 2011; Kozup et al., 2003; Mohr and Webb, 2005; Pino et al., 2016; Yoon and George, 2012).

In consideration of the above review, it has been illustrated the growing impact of eWOM on consumers' behaviour, as well as the importance and complexity of implementing diverse sustainability criteria in food products. In this line, if both approaches were bound, there would be a great opportunity that companies could exploit by focusing their communication efforts in those individuals who perform eWOM. Anyway, literature reveals that little is known whether a green or sustainable food-related eWOM actually exists, and if so, what its relevance is in terms of capacity of influence. These are the main reasons why a eWOM segmentation is strongly needed. Thus, the present study conducts an approach diving into web 2.0 and eWOM with reference to food issues, considered these within their wider spectrum: gastronomy, restaurants, cooking, products, etc. For that purpose, two main objectives are established:

1) Firstly, to perform a segmentation of authors of food-related eWOM based on their food-related lifestyle and determine whether there is, among them, a remarkable group displaying consistent sustainable features,

2) and secondly, if this condition is fulfilled, to verify whether the capacity of this group of interest to influence the behaviour of opinion seekers is higher than the other groups.

2. Methods

In order to address the aims previously pointed, it was conducted a survey study with a total sample of 428 authors of food-related blogs/videoblogs in Spanish. The sampling was conducted through random searches performed on 'Google' search engine (www.google.es) from March to June 2014, and authors were contacted via e-mail. In detail, the questionnaire was auto-administered online by respondents themselves but under control of SphinxOnline 3.1.2., software specialized in digital surveys. For more detailed information about methodological aspects, see Table 1.

Table 1. Technical data

Population	Authors of personal food-related weblogs/video-blogs
Sample size	428 individuals
Surveying technique	CAWI (computer aided web interview) Sampling method
	Simple random sampling
Sampling error (e)	±4.86%
Level of significance (α)	95.5% (p = q = .50) Date March to June 2014

All respondents answered voluntarily to a questionnaire composed of three main sections. The first section gathered information about the most basic demographic variables, gender, age, and level of education (Table 2)

Table 2.. Technical data

Sample size	428 individuals
Gender	Female: 79.6% Male: 20.4%
Age	From 19 to 29: 16.5% From 30 to 39: 44.1% From 40 to 49: 25.1% From 50 to 59: 11.1% 60 and older: 3.2%
Education	Elementary school: 7.3% Secondary school: 31.8% University: 46.8% Master/PhD: 14.0%

In second term, in order to determine and classify the food-related lifestyle depicted by respondents, and hence, also in the content they generate and spread through their blogs, it was included an adaptation of the Food-related Lifestyle instrument - FRL (Brunsø and Grunert, 1995; Brunsø et al., 2004) (see in Table 3). The FRL model has been widely and successfully applied to various European and non-European food cultures since its creation and its validity and reliability are beyond any doubt. This instrument attempts to explain behaviour toward food purchase through examining the food related lifestyle of individuals by looking at the importance of five interrelated aspects: ways of shopping, quality aspects for evaluating food products, meal preparation methods, consumption situations, and purchase motivations. The FRL adaptation consisted of 28 statements and the response modality took here the form of a Yes/No type question.

Finally, the third section was devoted to the measurement of centrality. Centrality is a sociometric measure, meaning that it requires the calculation of network data, in this instance relationships between individuals. Centrality (Wasserman and Faust, 2009) refers to the 'strategic position of an actor within a network' (p. 169), which makes him or her 'particularly visible to the other network actors' (p. 171). To this end, the most common procedure is to ask each respondent about the people they turn to or would turn to for information, affection, advice, help or financing, etc., depending on the case (Coleman et al., 1966; Requena-Santos, 1996; Rogers, 2003), standard practice being to state a specific number of contacts to be cited by each participant. Thus, with the aim of establishing links between participants, and consequently a data base with a grid structure, the individuals contacted were asked to answer the question: "Please name up to five blogs/video-blogs to which you most frequently turn or would turn to obtain information and/or to ask for advice about food-related topics, such as recipes, nutrition, restaurants, kitchen tools, etc."

Table 3. Technical data

Ways of shopping: - I read information labels and compare products. - Information from advertising helps me to make buying decisions. - I am influenced by what people say about food products. - I just love shopping for food. - I like buying food products in specialty food shops. - I always check prices. - Before I go shopping for food, I make a list of everything I need. Quality aspects:
- I prefer to buy natural products, i.e. products without preservatives. - I always try to get the best quality for the best price.

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- I like to try new, innovative foods.
- I always buy organically grown food products.
- I find the taste of food products important.
- I prefer fresh products to canned or frozenproducts.

- Cooking methods:
- I just love cooking.
- I like to try out new recipes.
- We use a lot of ready-to-eat foods in our household.
- I try to involve the whole family in meal chores.
- I always plan what we are going to eat a couple of days in advance.
- I consider the kitchen to be the woman's domain.

Consumption situations:
- I used to nibble between meal times.
- Going to restaurants is a regular part of my eating habits.
- I attempt to follow mealtimes.
- We often get together with friends/relatives to have dinner in a restaurant. Purchasing motives:
- I like to be praised for my cooking skills.
- Eating is to me a very exciting sensation.
- A traditional dish gives me a sense of security.
- I only buy and eat foods which are familiar to me.
- The most important thing when having dinner with friends, is that we are together.

Source: Adapted from Wycherley et al. (2008).

Once data were collected and processed, several techniques of analysis were performed to respond to the listed objectives. In that sense, by using the software SPSS version 24.0.0.1, it was conducted a k-means Cluster Analysis in order to segment respondents and an Analysis of Variance (ANOVA) to perform an intra-group comparison in reference to the different levels of centrality of participants (dependent variable) and the diverse groups risen from the cluster analysis (independent variable).

In turn, the calculation of the centrality indexes was performed using the algorithms included in the Ucinet 6.411 software package (Borgatti et al., 2002). Particularly, the specific centrality measure selected for the study was the eigenvector of geodesic distances. This measure represents an ideal function which enables the identification of the most central actors in terms of the global network structure considering the degree to which the relationship dimension of actors fits in with the global relationship dimension of the network (Bonacich, 2007). After that, these eigenvector figures were recoded into a one-to-five-point Likert-type scale running from 1 'Very low' to 5 'Very high' with the intent of gaining in intelligibility and better comparability with the other rates.

In the next section, main results are presented under two sections: first of all, the analysis of the different food-related lifestyle segments/contents, and after that, the study of the relation between levels of centrality and clusters.

3. Results and Discussion

3.1. Clustering

With the aim of accomplishing the first objective set at the end of section 3, a k-means Cluster Analysis was conducted in order to segment blog authors who were selected. After several preliminary trials, this statistical procedure distinguished three groups of individuals which come together through similarities in various FRL aspects. At the same time, up to ten statements of FRL instrument were not statistically significant, which means that these variables are not good enough to establish differences between respondents, being aspects equally shared by all of them.

Taking into account these not-significant statements, it can be stated that authors of food-related weblogs are, generally speaking, hardly impressionable by advertising and comments of other people about food topics. They all also like everything relating to the act of cooking itself (they love cooking, trying new products and recipes, and avoid purchasing ready-to-eat foods). Moreover, these people tend to have and enjoy meals at home with a strong social component. The authors of food-related weblogs attach, thus, great value to food.

Aside from this, there are particularities that justify a further distinction among them. On this point, as it was mentioned above, three differentiated groups were highlighted (Table 4). After interpreting and comparing characteristics and patterns of each cluster, different segments were labelled with the names *conservative savers*, *gourmets*, and *greens*.

Conservative savers, 35.04% of the sample (Table 4), are very price conscious and hence also the most interested in the price/quality relation (Table 5). *Conservative savers* pay quite attention to shopping lists and planning for menus. Moreover cooking, for this segment, does not have to be time-consuming and complex nor involve the whole family in it. They value social relationship aspects of having lunch/dinner the most, and they do so following mealtimes.

Gourmets represent 25.00% of the sample (Table 4). This group enjoy shopping for food the most and use specialty shops more than others (Table 5). On the other hand, this group is not as much concerned as the rest about prices. *Gourmets*, sybarite and hedonistic food consumers, consider taste as the most relevant indicator of quality. They also differ from other segments in their foresight, since these tend to be more impulsive and spontaneous when going shopping and planning menus. Eating between meals is not particularly common and social interaction at mealtimes is also important for this group.

Finally, *greens*, 34.81% of respondents (Table 4), are characterized by a strong interest in product information and quality aspects as healthiness, freshness, and ecology-naturalness (Table 5). In contrast, they attach the least value to taste of all segments. Eating between meals is not particularly common for this group. Moreover, *greens* are more price conscious and farsighted than *gourmets* but less compared to conservative savers. *Greens* also tend to involve the whole family in cooking tasks while the social side of eating for them is not, maybe, as much important as it is for the other segments.

Table 4. Clusters' size.

Clusters	Cases	Percentage
Conservative savers	150	35.04%
Gourmets	107	25.00%
Greens	149	34.81%
Missing	22	5.14%
Total sample	428	100%

Table 5. Significant FLR statements' scoring in clusters.

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FRL dimensions and statements	Cluster scores			p-value
	Conservative savers	Gourmets	Greens	
Ways of shopping				
I read information labels and compare products	,4	,5	,8*	,000**
I just love shopping for food	,6	,9*	,5	,000**
I like buying food products in specialty food shops	,1*	,6*	,3	,000**
I always check prices	,8*	,1*	,4	,000**
Before I go shopping for food, I make a list of everything I need	,7	,5*	,7	,003**
Quality aspects				
I prefer to buy natural products, ie products without preservatives	,7	,6	,9*	,000**
I always try to get the best quality for the best price	,9*	,4*	,5	,000**
I always buy organically grown food products	,1	,1	,8*	,000**
I find the taste of food products important	,5	,9*	,1*	,000**
I prefer fresh products to canned or frozen products	,4*	,6	,6	,000**
Cooking methods				
I try to involve the whole family in meal chores	,2*	,4	,5	,000**
I always plan what we are going to eat a couple of days in advance	,5*	,3	,3	,000**
Consumption situations				
I attempt to follow mealtimes	,9*	,7	,9*	,000**
Purchasing motives				
The most important thing when having dinner with friends, is that we are together	,8*	,7	,6	,012**

* Best characterize the segment (highest/lowest scores).

** Significance level of 95%.

At this point, once the data derived from cluster analysis has been interpreted, it can be reliably confirmed that the sample retrieved from the internet plays three differentiated and consistent food-related lifestyles (*conservative savers, gourmets,* and *greens*) which will guide the eWOM communication they emit through their own weblogs.

3.2. Group comparison

The mean scores obtained in the measurement of centrality with regard to the cluster each respondent belongs to are gathered in Figure 1. In general, respondents reported moderate levels of centrality with a downward tendency:
2.67 (1.00 min.; 5.00 max.) in case of *conservative savers*, 2.41 for *gourmets*, and 2.62 for *greens*.

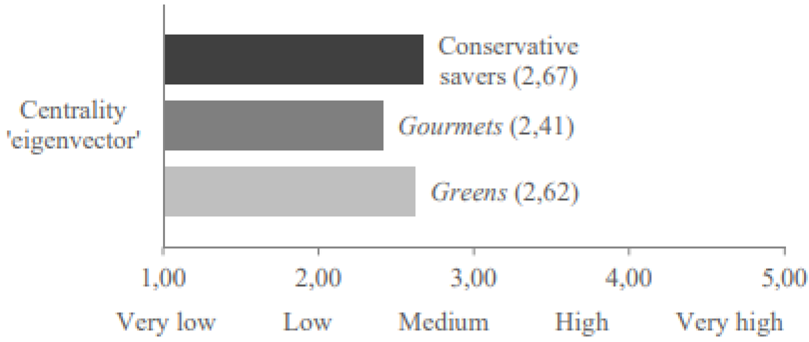

Figure 1. Mean scores of centrality measure

After this exploratory analysis, it was performed an ANOVA to test the effect of cluster membership (either to *conservative savers* group, or to *gourmets*, or to *greens*), considered as independent variable, on the capacity to influence others' behaviour or centrality level (1, very low; 2, low; 3, medium; 4, high; and 5, very high), considered as dependent variable. This analysis is justified by the possibility of existence of different levels of influence depending on the group of membership which would imply that all these three groups are not equally prominent or relevant on the food-related Web 2.0, especially *greens*, on whom this study is focused.

In this sense, it was not found any statistically significant difference by cluster membership with regard to the centrality levels according to a significance ratio of .05 (p = .381), as shown in Table 6. Presumably, this indicates that *greens* just as much as *conservative savers* and *gourmets* show the same power of influence when boosting the flow of information on the Internet about food-related issues by means of the contents of their blogs.

Table 6. SPSS output of ANOVA test

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Centrality	Sum of squares	df	Mean square	F	Sig. Between
groups	4,460	2	2,230	,968	,381**
Within groups	928,193	403	2,303		
Total	932,653	405			

* Levene Statistic = .121 (p = .886)

** p > .05 (not significative) Source: Authors.

4. Conclusions

This study has revealed information of great importance that reflects in implications for businesses and professionals in marketing.

Overall, the methodological approach used in the present paper is a pretty suitable way to examine the food consumption style of eWOM generators in a rather simple and efficient way. In reference to this latter, there is

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reason to believe that those aspects which are in tune with the preferences and opinions of these opinion leaders will most likely be supported and penalized, in contrast, those which are not.

The results of this paper also contribute to better understanding of influencing consumers' needs and their food-related lifestyles. The identification of three different consumer segments provides with clues to food industry to adjust production to these preponderant segments and their preferences in buying and consuming food. Moreover, this paper is as well of substantial help for marketers to design better adapted communication policies to these segments in order to perform more efficient diffusion campaigns. All of these are basic aspects that will have direct impact on sales and results. For this purpose, further research could be conducted on food-related lifestyles targeting some specific food categories, for instance, meat, vegetables, or convenience foods.

Concretely, with respect to the specific objectives set for the present study, findings support that at about one third of authors of food-related weblogs carry out sustainable patterns at the time of making their consumption decisions on food issues. However, it is also true that, according to the ANOVA test, these *green* consumers do not prove to exert higher levels of influence than *conservative savers* or *gourmets*.

This fact, referring to the focal point around which this study revolves, does not indicate that *conservative savers* or *gourmets* are not committed to sustainable production or not prone to sustainable behaviour performance, but maybe they simply are not willing to give up certain product attributes just to purchase green such as convenience, availability, price, quality, or taste. As mentioned in prior sections, the offer of sustainable products is a common concern to all consumers in a greater or lesser extent, so it is not surprising that the tone in the eWOM they emit may reflect this vein.

Altogether, eWOM must be viewed and treated as opportunity rather than a threat, since it enables a more efficient communication, capable of reaching a greater number of consumers. Direct contact with eWOM generators allows food producers to identify the consumers who talk about their products and services, to determine their profiles and to obtain first-hand information concerning comments with such a great effect on their corporate image. By gaining knowledge of eWOM in this way, industry will be able to face complex situations if necessary and to emit a suitable response to the market, which will lead to higher levels of trust and customer loyalty.

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A preliminary exploration of Sustainable food consumption in South Africa: Setting an agenda for Government policy

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Abstract

The status of current consumption is unsustainable as the rate of human consumption is higher than the capacity of Biosystems to renew. Unsustainability of food consumption severely affects one's day-to-day life and health; country's economy; welfare of society and capacity of environment w.r.t source and sink. The literature suggests that the issues of unsustainable food consumption cover challenges of both over-consumption and under-consumption. A young democracy like South Africa which is attempting to address impacts of historical injustices, food insecurity is a priority for the government. Ironically, food wastage is also very high in the country. This contradictory context makes it pertinent to prioritise discussions in the area of sustainable food consumption. Literature in this area suggests that consumption is not entirely individualistic process and government policies can direct the sustainable food consumption effectively. Hence, the paper examines the sustainable food consumption in South Africa; explain its background, characteristics, issues and journey so far to identify prospects and to establish agenda for government policies. This is a review-based paper which examines the theoretical literature in the area of sustainable food consumption and government policies and establishes importance and scope of government policies. It also investigates contextual literature on the sustainable food consumption, food insecurity and wastage in South Africa. The paper summarises and synthesises key insights emerging from the review after critical analysis. It further explores government policy initiatives through the framework given by Reisch, Eberle and Lorek, (2013). The paper clearly identifies that under- and over-consumptions are two poles of unsustainable consumption in South Africa and both demands equal and urgent attention of policy makers. It highlights that no single intervention is going to be enough or effective in handling these two extreme poles of consumption. A strong policy has to have coherent, integrated mix of various categories of interventions. The findings also indicate that there is a need for active and involved policy interventions. Being a young democracy, the process of establishing sustainable consumption policy frameworks and instruments is still taking shape in South Africa and the policy makers have flexibility to learn from the experiences of world economies and leapfrog. Moreover, the paper also stresses that the policy interventions which are developed respecting contextual background, food systems and current practices; considering integrative and interdependent nature of food system have more chances of success in managing two poles of sustainable consumption.

Keywords: Sustainable Food Consumption, South Africa, Government Policy, Food Insecurity, Food Waste

1. Introduction

Growing resource exploitation, current unsustainable consumption practices, limited sink capacity and slow rate of renewal of ecosystems is putting pressures on the earth's fragile systems which is creating a sense of urgency to address sustainability issues (Peattie and Collins 2009; Fisk 1973). Food and drink, housing, and transportation are the top three contributors to the growing pressures on the earth's ecosystems (Peattie and Collins, 2009). Food system influences the sustainability of earth's ecosystem through unsustainable practices at production, distribution, consumption stages. At the production stage unsustainable practices contribute to the loss of biodiversity, deforestation, desertification, degradation of soil deterioration of water quality and quantity (Von, Bormann, 2019). At the distribution stage, mismanagement of food supply chain creates food loss and at the stages of consumption its unavailability creates issues of food insecurity while its excess creates food waste and wastage (Food and Agriculture organization, 2013). This further adds to the loss of precious resources like water, energy, money, nutrition etc. besides adding to greenhouse gas emissions (WWF, 2017). There is no doubt that the all stages of food system are highly integrated and are important to address sustainability issues. However, for the purposes of this paper the focus of study will remain sustainable consumption and related aspects w.r.t food only.

The context for this paper is the South African Context which is a major economy of the region. Interestingly, in South Africa, both population and affluence are growing. However, it displays the highest level of inequality in the world (The World Bank, 2018); has approximately 27% unemployment (Euromonitor International, 2018; p23); growing urban population; unsustainable resources consumption patterns (UN Economic and Social Council, 2009). Adding to this the country is facing critical challenges of the food-energy-water nexus (Von Bormann, and Gulati, 2014). Over-consumption and materialistic tendencies are prevalent in higher-income groups while food insecurity insufficient access to resources, food insecurity can be witnessed among lower income groups (UN Economic and Social Council, 2009). Unsustainability of food consumption severely affects one's day-to-day life; health; country's economy; welfare of society and capacity of environment w.r.t source and sink. The literature suggests that the issues of unsustainable food consumption cover challenges of both over-consumption and under-consumption. A young democracy like South Africa which is attempting to address impacts of historical injustices, food insecurity is a priority for the government (Shisana et al. 2014). Ironically, food wastage is also very high in the country currently (WWF, 2017). This contradictory context in South Africa makes it pertinent to prioritize discussions in the area of sustainable food consumption. Literature in this area suggests that consumption is not entirely individualistic process and government policies are an important instrument to direct the sustainable food consumption effectively. Hence, the paper examines the sustainable food consumption in South Africa; explain its characteristics, drivers, issues and journey so far to identify prospects and to establish agenda for government policies.

On this backdrop, this chapter examines the possibilities for government policy to promote sustainable food consumption in South African context. The first section covers the nuances of sustainable food consumption to build understanding about the scope and impact. It the second section, background of unsustainable food systems in South Africa is presented to understand the way system contributes to unsustainability in food production and consumption. In the next section, unsustainability in the food consumption in South Africa is covered. The fourth section, public policies interventions in the area of sustainable food consumption are examined through the policy instruments framework given by Reisch et al., (2013). This further identifies emerging agenda items for strategy

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makers. In the following section the paper concludes with establishing integrative and complex nature of food systems and strongly suggests need for coherent, active and involved policy interventions.

2. Understanding Sustainable food consumption, its scope and impact

Sustainable food consumption covers absence of both under- and over-consumption and as a result deals with the issues of food insecurity to food wastage (WWF, 2017; Reisch et al., 2013; Food and Agriculture organization, 2013). Food security covers availability of safe and nutritious food, access to resources to acquire food, stability of access of food, adequate nutrition from food use (Food and Agriculture organization, 2006). Food loss is often defined as spoilage at the production, post-harvest and processing stages while food waste is food loss at the stage of retail distribution and consumption (WWF, 2017; Parfitt et al., 2010). Internationally, out of all food produced for human consumption, one third fall under category of food loss or waste (Food and Agriculture organization, 2013).

Food insecurity creates challenges of hunger, malnutrition, stunted growth among children, unsafe food, lack of dietary diversity and low immunity (Food and Agriculture organization, 2017 and 2013). Food loss and wastage give birth to challenges like pollution of land and water, greenhouse gases, wastage of nutrition, energy, water, finances (Food and Agriculture organization, 2017). Moreover, it adds to the problem of global food insecurity. It is important to highlight that the "*produced but uneaten food occupies almost 1.4 billion hectares of land*" which is approximately "*30 percent of the world's agriculture land*" (p6, Food and Agriculture organization, 2013).

On the other side, overconsumption of food is consumption exceeding ones needs which creates oversupply of nutrients and energy than required (Williams, 2016). The results of overconsumption of food can be witnessed in the form of growth of overweight population, obesity and non-communicable diseases (Seyfang and Paavola, 2008). Overconsumption adds to health problems and contributes to lifestyle and chronic diseases like obesity, diabetes, hypertension, heart disease, certain cancers, kidney stones, birth defects, mental illness to name a few (Farmer et al., 2017; Williams, 2016; Reisch et al., 2013). It is important to note that researchers are already warning that in the next decade more deaths will be due to non-communicable diseases caused by over nutrition than due to under nutrition. Moreover this may cost world economy "*$2 trillion per year*" and it also contributes to greenhouse gas emissions (p2, Williams, 2016). Moreover, the criticality of situation can be understood by the fact that the current trend where overweight adults (1.6 billion) are more than underweights (852 million) people (WHO, 2010).

3. Food systems in South Africa: Background

To understand unsustainability of food system in South Africa it is important to understand it from three perspectives of production, distribution and consumption. As far as production is concerned, South Africa has only 13% land is arable with only 3% is high potential land (p9, Von Bormann and Gulati, 2014). Ironically 87% of this arable land is still owned by white commercial farmers. This creates dualistic agrarian structure in SA and keeps small black farmers out of formal system. Moreover, there is a high degree of concentration in food sector which can be understood by the fact that 3% of farm grow 99% of country's food (p10). Similar oligopolistic situation and corporatization of agriculture continues to display even in seed and fertilizer markets. The report also indicates that the food production and pricing in the country is influenced by supply limitations, lack of diversified sources and price hikes in energy and water sector. This affects affordability of food which is a key element to ensure food security.

Similar situation can be witnessed in distribution sector where four retail chains are responsible for distribution of 55% of country's food. Literature indicates that this situation creates high barriers for small farmers, manufacturers and retailers if they want to become part of commercial formal food system. This dependency on few can become a major threat to country's food security. Although these formal or large-scale retailers ensure quality and food safety through standardization they also promote usage of refined food which is low in fiber and high in fat (Pereira, 2014).

As far as consumption is concerned literature suggests that the unsustainability of food consumption in SA is driven by oligopolistic agriculture and retail industry, historical divide w.r.t land ownerships, rapid urbanization, growing materialistic consumption in affluence class and limited understanding about food safety and waste. In South Africa, around 60% population lives in urban areas. Urban consumers are distanced from fresh produce, have easy access to convenience product, fast food and restaurant meal which are low in micronutrients and fibre, energy dense and high in simple sugar and salt (Reisch et al., 2013). Moreover, in the country, processed nutrient deficient, energy dense food with saturated fat, synthetic additive, preservative, added salt and sugar are easily available, affordable and socially acceptable (Von Bormann, 2019). Urban consumers often shift diets from traditional cereals and tubers to processed food and this "nutrition transition" with urban stressed and sedentary lifestyle lead to problems associated with over-consumption (Williams, 2016). In the country, demand for fast food is growing (Pereira, 2014) and so are issues of overconsumption and wastage.

Another aspect of unsustainability of food is related with food safety which covers health risk due to unwanted and unhealthy substances in food like pesticide, heavy metal, containments, pathogens, food additives, active hormonal substance etc.; basically aspects of quality of food which affects well-being of population of a country (Reisch et al., 2013). In SA, food safety and quality control systems are fragmented among "*the Department of Health (Food Inspection Services), the Department of Agriculture, Forestry and Fisheries (Perishable Products Export Control Board); and, the Department of Trade and Industry (South African Bureau of Standards)"* (p17, DSD & DAFF, 2013).

4. Unsustainability in food consumption in South Africa

South Africa like any other developing countries is facing issues of food insecurity, food loss and food waste and wastage. Food insecurity in forms of unavailability of safe and nutritious food, inaccessibility to resources to buy such food and poor quality of food is prevalent. As In sub-Saharan Africa, 44% population suffers from food insecurity (Shopouri et al, 2011). As far as South Africa is concerned, status is moderate as its "*45.6%" population was food secure, 28.3% was at risk of hunger and 26.0% experienced hunger*" (p 144, Shisana et al. 2014). Food insecurity is prevalent both in urban and rural areas. Historical injustices still reflect across the racial profiles where "*30.3% black African have food insecurity, 13.1% coloured, 8.6% Indian/Asian and only 1.3% white have food insecurity*" (p 145, Shisana et al. 2014).

Like other developing countries, in South Africa, food loss often occur at the production and distribution stages than during the consumption stage (Food and Agriculture organization, 2011). Green House gas emissions due to food loss is highest at post-harvest /processing /distribution stage in Sub-Saharan Africa (Food and Agriculture

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organization, 2016).

Food waste is that food which is not consumed due to deterioration or is discarded due to expiry. In South Africa, there is lacks of awareness and knowledge about food waste at household level. In the country, total costs of food waste throughout the food value chain is approximately "*R 61.5 billion per year"* which is roughly "*2.1% of South Africa's annual GDP"; out of which R 6 billion per year arises at consumer or household level* (p15, Nahman and de Lange, 2013).

As far as South Africa is concerned, overconsumption is prevalent and its impacts can be seen in overweight population where 29% of men and 57% of women are overweight or obese (Food and Agriculture organization, 2012). It is interesting to note that besides being overweight, many are nutritionally insecure in absence of balanced diets which is either due to choices or due to the issue of affordability (Metelerkamp, 2014).

5.Government policy and sustainable food consumption: Interventions, Limitations and emerging agenda items

Governments facilitate the sustainable consumption by creating enabling policies and infrastructure to facilitate sustainable choices (Reisch, Eberle and Lorek, 2013). Governments deploy both rewards and punitive methods in form of subsidies, taxes and regulations to direct and motivate sustainable food consumption practices. Moreover, visionary governments attempt to create an environment which makes sustainable consumption practices attractive and rewarding.

Looking at South African scenario, it emerged that the under-consumption aspect of sustainable consumption is addressed under food security policy while issues related to some over-consumption under health policies. In SA, these strategic government interventions are scattered across departments like nutrition programme, food based dietary guidelines and strategic plan for prevention and control of non-communicable diseases and obesity are interventions by the department of health; establishment of integrated food security strategy (IFSS) and zero hunger programme were interventions by department of Agriculture, Forestry and Fisheries (DAFF); national school nutrition programme were interventions by department of basic education; tax exemption from basic food were by SARS and NAMC; food and nutrition policy (2013) by department of social development and DAFF (Schönfeldt, 2015).

Reisch et al., (2013) suggested four types of public policy instruments to policy makers (a) information based, (b) Market-based, (c) regulatory and (d) "nudging" and also indicated that for effectiveness these instruments should be used in a coherent manner. In the light of review above, when strategic interventions to address sustainable food consumption of South African government are examined through the framework of policy instruments given by Reisch et al., (2013) following points emerge:

- It emerged that most of the government interventions are focused on managing issues related to sustainable production and there is need for more focus on interventions to address sustainable consumption.
- The efforts in the area of sustainable consumption are skewed towards addressing food insecurity issues. This indicates need of more efforts in the area of over-consumption which is becoming urgent due to rapid growth in health and social problems associated with over-consumption like obesity and non-

communicable diseases (WHO, 2010).

- The information policy instruments create awareness through various campaigns and labelling (Seyfang and Paavola, 2008). In case of SA, there is need to develop quality standards and mandatory labels which preferably are comprehensive (one label providing information about GMO, organically grown,

nutritional value, safety etc.) and preferably certified and verified by government agencies (OECD, 2008). This will help in building trust and will simplify identification of green and sustainable products.

- As far as market-based interventions are concerned, government need to come up with taxes which can be applied on junk food, fat rich diets, carbonated drinks, waste management etc. (WWF, 2017; Jackson, 2005). Since taxing unsustainable consumption is not going to be enough, therefore, policy makers should also try and motivate sustainable practices through providing subsidies like subsidy for organic production and consumption, for making healthy alternative available at competitive prices etc. However, it is important to mention that the market- based instruments needs continuous monitoring to ensure effectiveness (OECD, 2008).
- As far as regulatory interventions are concerned a lot of work has been started in South Africa. However, there is a need to set clear and measurable targets for different policies. Doing so can be effective if applied in waste management, in promoting sustainable procurement of local and green in government departments (public procurement). Regulatory interventions also can be used to create code of conducts for food related industries like retail, advertising etc. (Reisch et al., 2013).
- Nudging instruments are more voluntary in nature which facilitates choices and where "*default outcome can be the desired outcome*" (p 15, Reisch et al., 2013) can be incorporated in consumer policy which softly directs consumers to opt for sustainable choices (OECD, 2008).
- Due to multi-dimensional nature of sustainable consumption, contextual complexity and availability of learning from developed countries it would be advisable for South African government to create one integrative policy platform like consumer policy for all sustainable consumption related initiatives (Reisch et al., 2013; Jackson, 2005).
- It was noted that though consumers display positive attitude towards sustainable consumption; it is not reflected in their behavior. Therefore, public policies can look at specific areas of availability, affordability, quality, promoting and monitoring ecolabels (Prothero et al., 2011). They can also focus on less explored aspects of consumption like usage, product life extension and disposal.
- Social acceptance of sustainable food consumption can help in promoting sustainable behaviour. In this regard, there is a need for macro approach to change in public policies which can be politically activated, where educational institutions like school and universities make public aware about the limit to growth and fragility of biosphere and promote sustainable consumption practices to become new normal (Prothero et al., 2011). Besides these efforts, South African government can initiate, support and promote community led-initiatives (Jackson, 2005) to change consumption habits towards sustainability.
- Context affects sustainable consumption (Assadourian, 2010; Dolan, 2002) and policy makers need to identify priorities of sustainable consumption in South Africa and mechanism to address through

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policies over time.

- In order to promote sustainable consumption, consumers need to be empowered with skills and knowledge to critically analyze consumption practices and to understand that sustainable consumption practices are part of their civic duties, making them aware of social consequences of consumption, their rights and duties (Prothero et al., 2011). Therefore, policy makers should investigate how instruments can contribute empowering consumers in South Africa in this regard. Further a research enquiry may

  help in understanding how trust can be built in environmental standards through public policies (Schaefer and Crane, 2005).
- In South Africa, food wastage was observed very high (Nahman et al., 2012) and this requires immediate intervention at policy level. However, government will need participation of other institutions like private sector, consumer societies and other social institutions which makes it one of the major emerging research themes.
- The easy availability, social acceptance and affordability of nutrient deficient and energy dense food is prominent under oligopolistic retail environment (Von Bormann, 2019). Therefore, policy makers will benefit by knowledge about the way promotions by these retailers affect food practices of consumers. In this regard, impact and reach of social media in influencing food choices of youth can be an effective avenue for a policy intervention.
- SA is community-oriented society where communal, religious and social organizations have strong influence of people's lifestyles. Since consumption is influenced by social acceptance (Purushottam, 2019; Selsky and Parker, 2005), Policy strategist may explore possible ways public policies collaborate with society in educating public and in creating positivity about sustainable consumption.
- To understand barriers to sustainable consumption is important to facilitate consumption (Prothero et al., 2011). The barriers are influenced by context like review done so far suggests that the food system and food environment are different in South Africa (Von Bormann, 2019). Therefore, public policy identifying and addressing barriers can add momentum to the efforts to promote sustainable food consumption.
- The way South African government will design its priorities and will address simultaneous challenges of over-consumption through 'quality in limit' and food insecurity through 'sufficiency with quality' (Spangenberg, 2014) can be an interesting area to focus. Policy strategists may look at defining consumption space with its ceiling and floor which will help in making interventions more effective like it will be easier to moderate over-consumption groups to create some free space for the group in the areas of under-consumption (Akenji, 2014).
- Government can be more effective by focusing on unsustainability in their own operations; other large corporate organizations and the specific sectors which are main contributors to unsustainable consumption (Prothero et al., 2011).

6. Conclusions

The paper is developed with an understanding that consumption is not entirely individualistic; policy interventions have to regard social and psychological aspects of consumption and need to be coherent and interlinked policy (Von Bormann, 2019). Therefore, it highlights a need for more active and involved policy interventions. The paper clearly identifies that under- and over-consumptions are two poles of unsustainable consumption in South Africa and both demands equal and urgent attention of policy makers. It also highlights that no single intervention is going to be enough or effective in handling the two extreme poles of consumption. A strong policy has to have mix of all four categories of interventions (information based, Market-based, regulatory and "nudging" as suggested by Reisch et al., 2013). Looking at the rate of growth of non-communicable diseases the need to accelerate the pace of interventions in this area has clearly emerged. It strongly suggests to have coherent, proactive, evidence and research based, context empathetic, integrative, flexible and cross–sectoral policy to address challenges of unsustainable consumption.

Being a young democracy South Africa is still in a process of establishing policy frameworks and instruments so the policy makers have flexibility to rapidly build flexible systems on the experiences of world economies in this regard. The policy interventions which are developed in consideration with contextual background and current practice (Middlemiss, 2010); which are developed considering integrative and interdependent nature of food system (Reisch et al., 2013) have more chances of success in managing two poles of sustainable consumption.

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Green and inclusive entrereneurship

Boosting co-creation practices in makespaces to support the design of more empowering and circular food systems at a neighbourhood scale

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Abstract

The Fab Lab network is newly engaged in several projects that involve the idea of rethinking sustainability, re-localizing manufacturing and promoting a collaborative learning culture. Fab Labs, as makespaces, are now perceived as key spaces for actively developing practical knowledge and create interactions with local stakeholders toward a more sustainable and redistributed manufacturing. In this respect, makespaces are encouraged to redefine its relationship with the local ecosystem by exploring questions such as: What are the effective interactions with local communities? How to build local interventions for enabling more emerging futures?

The paper aims at exploring what could be the role of co-creation in local context actions and what could be the community services developed in collaboration with makespaces for supporting the transition towards more circular cities. The results are based on an ongoing action-research at Fab Lab Barcelona called "El Barri Circular", which is designed in the frame of the EU-SISCODE project[1] as a 18th month co-creation process about circular practices in the neighbourhood of Poblenou. This pilot has been engaging local stakeholders to create synergies in the specific context of food. The pilot used a set of design and co-creation methodologies to support a transition towards re-valuing surplus food and bio-waste at the neighbourhood scale.

Over the project, *El Barri Circular* has collaborated with local km0 restaurants, cooperatives, local associations, urban gardens, and makers' community and engaged more specifically with three circular community projects connected to the food value chain: food waste redistribution, bio-waste-based material development and collective composting. Four interdependent types of community services for circular systems were imagined, and will now be co-produced and tested at the neighbourhood level: a set of learning and co-designed activities to support the local design and production of dedicated tools, a logistical service for food waste collection-processing and community engagement and an environmental monitoring system that measures the flow of materials, energy and resources in the local food system.

The project outputs will be discussed within broader networks and feed a collective handbook that will contribute to envision the design of new circular practices in makespaces and thus, shape new forms of learning in local areas.

Keywords: Fab Labs, Co-creation, Community Engagement, Sustainable Education, Eco-design

[1] https://siscodeproject.eu/

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1. Introduction

Makespaces as enabling spaces for local circular transformations

Circularity is one core value present in the manifesto of the Fab City network (Diez, 2018). The key guiding principles of Fab City are aligned with the primary directives of the Circular Economy Action Plan by contributing to the reduction of municipal waste and packaging by 2030 (Diez, 2017). Barcelona is one of the pioneers of the Fab City network. In July 2014, the city hosted the Fab10 annual conference in which Fab City Global Initiative was officially launched. In this occasion, the Barcelona City Council committed to the goal of producing locally half of everything consumed in the city by 2054. This initiative proposes a model for cities to be resilient, productive and self-sufficient in order to respond to the current societal challenges. It also aims at recovering the knowledge and the capacity to make things and empower citizens to become the leading agents of their own destiny.

At a local scale, Fab City initiative boost the use of community production spaces as hubs to connect citizens with existing products and services that foster new sustainable practices in consumption and production. According to Stewart and Tooze's definition (Stewart and Tooze, 2018), 'makespace' can be used as a catch-all term for an open access community fabrication workshop regrouping Fab Labs, Hackerspaces, (Re)Makespaces and other facilities with a suite of fabrication tools and technologies openly accessible for use by a community.

Meeting local needs through local inventiveness, these spaces have a great potential to foster synergies between different actors in a territory using open source and redistributed fabrication. Dewberry et al. (2017) asserts that a form of redistributed manufacturing composed of new, localised structures of design and manufacturing, could enable large reductions in resource consumption by limiting waste in a supply chain, and through addressing the flows of resources at critical times in the lifecycle of products.

The maker network has been growing empowering people and offering enabling opportunities through digital social innovation strategies. By developing research programs, maker communities are helping to create blueprints for a new generation of prototypes that are tailored to local circumstances. Following the idea of bringing opportunities for people to develop innovative solutions, the present study describes the combination of two methodologies to foster eco-innovative practices enabling citizens to develop skills and knowledge for territorial circular transformations.

Responsible Research Innovation and co-creation practices to support local community transformations

Responsible research and innovation (RRI) and co-creation have been considered as potential approaches to engage citizens and different levels of decision making authorities in collaborative processes. Responsible research and innovation (RRI) is a concept that has recently gained currency, particularly in Europe. According to the European Commission (2014), RRI means that societal actors work together during the whole research and innovation process in order to better align both the process and its outcomes, with the values, needs and expectations of European society. Von Schomberg (2013) defines RRI as a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products.

Recently RRI literature have introduced the perspective of co-creation, with the aim to associate these two areas of knowledge and cross potential connections between them. Co-creation methodologies, when applied in RRI, have the potential to efficiently engage citizens and civil society organizations, bringing on board the widest diversity of actors normally excluded from making decisions, on matters of science and innovation. Co-creation is defined as the participation of end-users in the process of innovation (von Hippel, 1987), in which knowledge and solutions are co-produced by different actors working in synergy, in an inclusive process for civil society and citizens (Regeer & Bunders, 2009).

Adapting the use of co-creation in RRI as a bottom-up approach to address local solutions, Fab Lab Barcelona has been developing a pilot within SISCODE EU project applying co-design tools to find a common language among different participants. SISCODE is an H2020-EU funded project aimed at stimulating the use of co-creation methodologies in policy design, using bottom-up design-driven methodologies to pollinate Responsible Research and Innovation (RRI), and Science Technology and Innovation (STI) Policies. The project looks for new ways to reach the gap between grassroots, citizen initiatives and policy design when facing societal challenges. The assumption is that "Labs" (Fab Labs, Living Labs, and Science Galleries) could play an important role in creating bridges and activating the desired societal changes. 10 pilots are being conducted in 10 different EU places through the implementation of co-creation journeys that last around 18 months. In these experiments, each lab aims to tackle a specific societal challenge, (meaningful for the context in which the lab is located but at the same time transversal and relevant at a wider scale) and engage with it a set of stakeholders in a co-creation process from the stage of co-design where stakeholders are analysing the context, reframing the problem and envision alternatives, to that of co-production of prototypes within an iterative process. (Real et al., 2019; Rizzo et al., 2018)

El Barri Circular: from co-creation to the emergence of a new synergistic system for local food cycles

The Fab Lab Barcelona's pilot has been exploring how co-creation and RRI can be approached to locally develop solutions to improve the circularity of surplus food and bio-waste at a neighbourhood scale. The main challenge started by exploring the following question: **How to endeavour a circular economy in the neighbourhood by co-producing projects that connect local resources and territorial needs?**

"El Barri Circular", which means "the circular neighbourhood", by mixing Spanish and Catalan languages, has been engaging local stakeholders at different levels to create synergies between existing initiatives related to the food system. The pilot aims to stimulate the use of co-creation methodologies, through an active learning process, to support a transition towards re-valuing surplus food and bio-waste at the neighbourhood scale.

After six months of exploration and learning, the core network of stakeholders has designed a "synergistic system for local food cycles. The system is acting at the neighbourhood level in collaboration with local stakeholders, and include ongoing food waste generators in the co-development of three circular community projects proposing food waste redistribution, bio-waste-based material development and collective composting activities. To activate and enhance the community empowerment and circular knowledge capacity building, three types of community services have been imagined. These include: a logistical service for food waste collection and community engagement, a set of learning practices to support the local design and production of dedicated tools, and an environmental plan that measures the flow of materials, energy and resources in the local food system. The system model will be developed and tested in Poblenou, the maker district of Barcelona in further steps.

This case study presents the "El Barri Circular" journey as an example of how to use co-creation and RRI into the innovation process to locally develop solutions to improve the circularity of a territory. The paper will first describe the co-creation process and then give an overview and discuss the emerging synergistic system for

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supporting the development of local food cycles.

2. Method: The co-creation process

Co-creation combined with Responsible Research Innovation was adopted for this study to develop deeper understanding of community engagement and its role in finding solutions to address local issues regarding surplus food and bio-waste. The research strategy is based on a specific neighbourhood, known as the maker and creative area of Barcelona, the district of Poblenou. Fab City Global Initiative has already started a first exploration in this territory, in which a prototype of a productive and scalable city has been tested. The initial idea aimed to contribute to the city's reindustrialisation through activities, services and projects that promote interaction between local communities and citizen initiatives. Following the same principles of people-centred, inclusive and locally productive approaches, *El Barri Circular* has been applying participatory design and learning by doing experiences to co-create and empower citizens as drivers for change.

'The experimentation was based on a methodology divided into 4 phases (Real, 2019; Rizzo, 2018) in which social innovation was fostered through the use of co-creation to combat local challenges: 1. Analysing the context, 2. Reframing the problem, 3. Envision alternatives, 4. Selecting the idea. The main stakeholders involved in this process were represented by local markets and km0 restaurants, cooperatives, local association’s urban gardens, composting initiatives, projects with food redistribution, makers and material designers.

- The first phase consisted of ‘analysing the context’ by having a better understanding of the existing instruments for circular economy, identifying the policies about food cycles at the different local scales and analysing the dynamism of Poblenou neighbourhood and Barcelona. For this phase, the Fab Lab’s team participated in 5 policy making events, 35 informal interviews with 50 local actors in order to identify the ongoing policies and resources that are participating in the local circular transition. Moreover, an effort has been done to develop a consistent mapping of current initiatives related to circular economy. The mapping phase focused on spreading awareness about ongoing activities and projects developed at Fab Lab Barcelona that are related to co-creation activities and empowerment of citizens through sustainable and regenerative cities.
- The second phase consisted of ‘reframing the problem’ through a shaping of the set of data collected to better structure the future interventions with local stakeholders. A first co-creation workshop named “Synergy Soup” was proposed (called “Sopa de Sinergias) destined to a core group of local stakeholders identified through the different interviews, events and participative observations. The event aimed at identifying synergies among the actors by matching local resources with local needs from each stakeholder. The workshop was built upon existing systemic design methodologies regrouping industrial symbiosis identification tools (Van Capelleveen et al., 2018; Makinen, 2018), resource mapping, input-output system modelling (Bistagnino et al, 2010; Barbero et al.; 2017). It was composed by four activities: (1) a presentation of the context and key aspects of circular design; (2) an icebreaker where participants were engaged in the preparation of the soup presenting themselves, picking some pre-cut vegetables and commenting their subjectivity by associating shape, colour to their emotion and personal inspirations. (3) Then, they were divided in three subgroups and were asked to first identify local needs and resources at individual, organisational and neighbourhood level and second to create projects that are matching identified resources and needs. They were playing on cardboards with three types of cards to fill (needs, resources, and projects) and advertisement paper collected and reused to be cut into lines to help them build and show the different connexions. Finally each group made a restitution while note-taking and soup distribution were offered by the two facilitators. The workshop permits to identify 58 needs, 36 resources and 31 ideas of projects were

generated by participants. It allowed getting to know each other and start creating shared value and a sense of community. After this event, the team developed and proposed a new plan of co-creation activities to guarantee an effective engagement and collaboration of the local community through an action learning process. The communication plan was redefined according to the target identified. An identity for the pilot was created and named *"El Barri Circular #Poblenou, episod: Food, waste and local crafts.*" Social media channels and personal invitations have permitted to maintain the engagement of the core group of stakeholders while opening the challenge more broadly to the community.

- The third phase which consists in "envisioning alternatives", was composed of five events during one month, in which the participants of *El Barri Circular* were actively involved to foster ideation and participate to learning experiences. The first event was a community ideation workshop which took place at an historic community place, "El Ateneu de la Flor de Maig"[2] where 5 pre-identified projects were challenged in groups through three short activities: First, participants used a customised version of the 6W tools to define the ideal solution of each concept and cross the different visions; Secondly, the facilitators created a new specific onion diagram that can be described as a back casting-value opportunity mapping challenging "how" to reach the solution, and identifying needs and opportunities in terms of materials, tools, resources and skills, and other project dimensions. After this problem definition activity, each group was asked to design idea cards adapted from the n to describe from 1 to 3 concepts framing diverse actions that could redefine and facilitate the development of the project. Finally a restitution of each group were realised. The community ideation workshop was followed by two learning by doing experiences, which were proposed and co-organised with local participants to raise knowledge and answer the need to "make things together". The Fab Textiles[3] ran a workshop for realising biomaterials and bio-composites from local waste collected in restaurants. Three techniques were explored by the participants: 3D extrusion, bioplastic sheets and bowls mold design. The second experience was facilitated by MACUS Cooperative[4], based on digital fabrication tools and machine design. The fourth event was composed by a session of co-design and scenario building, together with three stakeholders. The workshop was proposed during a local event about circular economy which took place in Palo Alto Foundation[5], another historical place of Poblenou. The workshop aims at understanding better the impact of food waste valorisation processes and designing new scenarios for local valorisation and supports. It was divided in three steps starting by the presentation and exhibition of three different initiatives using bio waste and food surplus. Then, each process was screened onto table where people, in groups used specific stickers for identifying the environmental impact at different stages of the process. This was inspired by simplified eco-designed tools such as LIDs eco-design wheel (Brezet et al., (1997)) or Material, Energy, Toxicity (MET) matrix (Gertsakis, 1997). The last part consisted in creating emotional narratives so to support new visions and services in the neighbourhoods to envision local logistic, educational services and new bank-time systems. Specific co-creation tools (Personas and moodboards) were given to participants to support them in scenario design. Finally, a last event was organised - the "convivial agora" in collaboration with the 40 students of the summer school of Degrowth[6] to go beyond environmental issues and discussing about the conviviality of the emerging projects. The event was designed with one context and theoretical presentation, one co-creation workshop and one larger public debate. The co-creation workshop has been

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2 https://ateneuflordemaig.wordpress.com/(Accessed on 28/08/2019)
3 https://fabtextiles.org/(Accessed on 28/08/2019)
4 https://www.facebook.com/M4CUS/(Accessed on 28/08/2019)
5 https://paloalto.barcelona/taller-barri-circular(Accessed on 28/08/2019)
6 https://summerschool.degrowth.org/ (Accessed on 28/08/2019)

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designed within the inspirational frame of the design tools for conviviality (Lizarralde and Tyl, 2017; Real et al., 2018; Vetter, 2017).

Through all these events, the internal team in collaboration with external stakeholders defined and refined a synergistic model for supporting local food waste transformation in the neighbourhood. The model is described below.

Results and Discussion: Toward a new synergistic system for local food waste transformation

The model is aimed at synthesizing the vision shared within the first three phases of the project to support circular food transformations at a neighbourhood scale. By identifying and co-designing with the local stakeholders as well as observing and raising knowledge about the food cycles, four community services have been identified, will be designed and experimented in further steps.

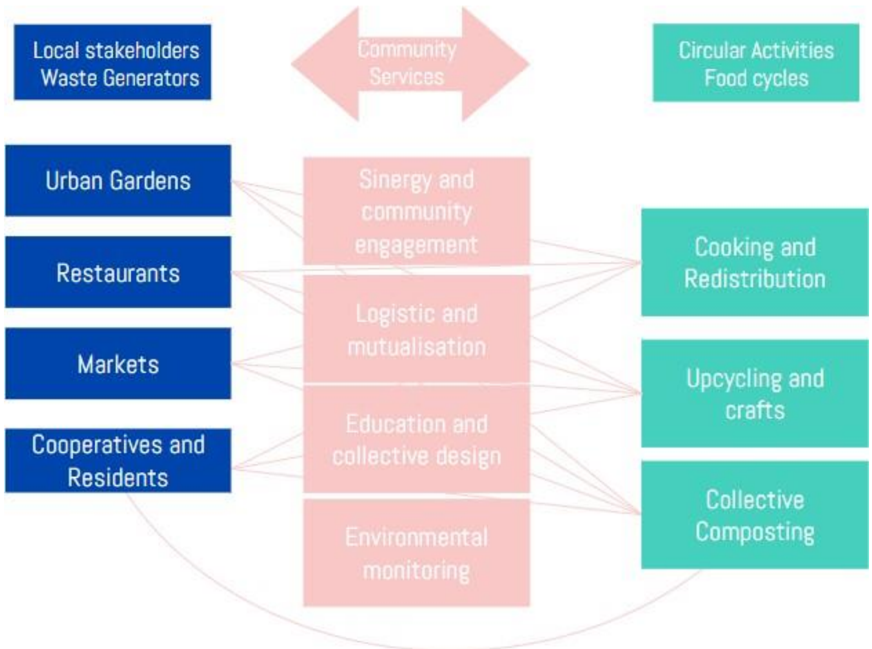

Figure 1. *Synergistic system for local food waste transformation*

Four type of stakeholders have been categorised as potential enactors of circular food shifts in the neighbourhood of Poblenou: (1) Urban Gardens as mixed and heterogeneous places where people are reconnecting with nature, experiments techniques, organise events for both creating social bonds and raise knowledge and discussions about environmental and health issues; (2) restaurants and (3) markets in the dynamic of building sustainable alternatives (with km O and slow food networks), (4) food cooperatives, particularly active in Barcelona and Catalonia (Espelt, 2013) where part of local residents are building self-organised groups that connects local producers and consumers with a short loop and historical Catalan cooperativism principles. Seeing as well generator of waste and actors of changes, these stakeholders are weaving an important amount of the local food waste.

Three **circular activities** have been selected, simplified from the food waste hierarchy (Papargyropoulou, 2014) and adapted for the specificities of the neighbourhood scale (Poblenou in that case).

- First, the activity of *cooking and redistributing food surplus* has been found through diverse practices: internally into families or communities, through sharing applications or within social organisations. One specific initiative caught up our attention as a promising social initiatives. The “Bacuinetes from

BarcelonaActua"[7] is a collective of grandmothers and local people (often in social difficulties) who collect and cook once a week the food surplus collected in local shops and distribute them in a collective meals organised for people in needs each week. Social associations from the city and neighbourhoods are supporting the initiative by connecting people and providers as well as booking a kitchen place each week.

- Another activity concerns *the design of materials and products based on food waste* with craft and innovative production techniques. This activity is generally under-explored at such a small scale. However, an opportunity has been identified with the strong presence of artisans and makers locally and the wish to tend to enhance the autonomy of citizens by allowing them to be aware of how things are made, to design products and to have access to the means of production. The Fab Textiles and others makers are yet experimenting in material innovations from food waste and look after new modes of production more distributed. Within the first workshop, several techniques have been tested to create biomaterials and bio composites from coffee, orange, yucca peels as well as eggs and mussels shells.
- The third circular activity is the *experimentation of effective compost techniques at individual, building and neighbourhood scale*. Several possibilities have been already provided by the city like municipal organic waste collection point, the distribution of collective compost bins in building. Another technique, the worm compost system is being experimented in a local urban garden, using waste from residents, local restaurants and markets with a semi-industrial worm composting to create compost distributed for local gardens and others uses to turn green the local area.

To maintain, support and scale up this grassroots initiatives at the neighbourhood level, four types of community services have been imagined from the emerging needs of local stakeholders i.e. services for community building, logistic, making education and environmental monitoring.

- First, stakeholders identified a necessity for re-connecting people, informing them as well as opening or promoting existing spaces and events for encouraging *community synergy building*. The service will be built upon collaborations with the stakeholders to access to the diversity of places present in the neighbourhood that could be private or public, to communicate about and participate in local events, to create new moments for synergy emergence, where co-creation tools can be shared and used in an open way.
- Another need is about *logistics* questioning how to integrate in the actual system and habits of stakeholders the possibility for them to be active in the local food waste transformations. The logistic system consists of collecting waste in restaurants and markets, processing them and finally re-distributing meals, products and composts. This requires a preparation phase for organising people and tasks while providing necessary tools to make it possible. Three actions are proposed before launching the service:
  - Designing a shared soft mobility device (a cargo-bike) that permits to transport bio-wastes, products and materials from one point to another.
  - discover and discuss material innovation possibilities, to best select the type of waste, the disposal
  - Gathering bio-waste providers (restaurants and markets) around a series of meetings aimed to
  - devices and storage of resources and finally to agree on a schedule.

[7] http://www.barcelonactua.org/ca/proyecto-exito-BACuinetes (Accessed on 28/08/2019)

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- Devices or organisational mechanisms could be developed to gather the list of community tasks to be done and connect them to local stakeholders, making them accessible through micro-volunteering platforms or other forms of collaborations that ensure and diversify their effective engagement. Local stakeholders want experiences to learn by doing, so to improve their internal capacity and go beyond

- cognitive gaps and individual learning limits. Educational services are composed by a set of learning and co-designed activities that support the local design and co-production of dedicated tools needed to feed local food waste transformations. In the case of cooking, material innovation or composting, specific workshops could be realised in cooperation with the local expertise, from practicing bio-material recipes from existing database, to the design of new ideas via co-creation tools, to building moulds with digital fabrication tools. Collective co-development could be organised like the realisation of a cargo-bike system that is made with self-helped bike workshop.

- The last service is about *environmental monitoring* and suppose the exploration on how to measure the flow of material, energy and resources for the emerging local food system. An essential step towards achieving a relevant model of circularity at the neighbourhood scale is gaining a better understanding of the evolution of the environmental impacts from the existing to the new emerging multi-loop systems. First measures from material analysis flow can be done at the prototype level and scenario of upscaling could be then debated in collaboration with other studies and emergent work from other scales.

3.Conclusions

The case-study shows that co-creation methodologies have permitted to engage local stakeholders, support them to adopt new practices and co-design a contextual set of services for encouraging local food waste at the neighbourhood level. It highlights the complexity of local transformations and underlies the hypothesis that makespaces can participate in supporting the design and development of local circular ecosystems, thanks to an activist mindset, a knowledge-making culture and global connexions. In the project El Barri Circular, the makespace was piloting the co-creation process connecting local initiatives in a global societal challenge.

An important and emergent aspect for such initiative remains the stakeholder engagement process and respective design activities that supported it. Indeed, the evolution of the process and its results in this case was highly dependent of the synergies established with local stakeholders combined with the tools and methods shared within the EU SISCODE project. Starting with an understanding of the actual ecosystem was crucial to strengthen connection between actors and promote collaboratively actions, supporting existing initiatives. From the identification of stakeholders and initiatives, the immersive visits to the synergy mapping and ideation workshops, the stakeholder engagement process, was like the divergence and convergence phases of design processes, enlarging and consolidating the active network. Through discussions and events, the initial concepts have been transformed, the emerging model has gained in legitimacy.

The synergistic model for local food waste transformations is proposing to co-produce with local stakeholders services for community building, logistic, making education and environmental monitoring to optimise how food waste are redistributed and transformed in meals, materials, products and compost. A new playground is now being developed to make the proposal tangible, and define more precisely what could be the role of makespaces in the system and how to revisit the interactions between the quintuple helix of stakeholders, meaning public bodies, the civil society, residents, economic actors and academics. According to the specific context, answers could be different from makespace-leaded initiatives, public-leaded actions to self-organized ecosystems in neighbourhoods.

The project outputs will be discussed within broader networks and feed a collective handbook that will contribute to envision the design of new circular practices in makespaces and thus, shape new forms of learning in local areas. There is an interest to adapt such processes in other sectors or even to let it open to transversal applications. This weak signals will be also reinforced by replicating it in other neighbourhoods considering the specificities of the context (cultural, political, economic, and demographic), as well as creating connexions with other scales, specifically at the city and regional levels. Those interactions can help to avoid new forms of disconnexions, distances and dispersions between people in territories.

Creating new forms of values for territories through co-creation is a constant engagement for reaching RRI values. It consists of making more efforts towards inclusion, transparency and openness while adopting new postures to be aware of the potential barriers and conflicts behind system development, and looking for overcoming emergent frustrations that can create more convivial and sustainable environments. Encouraging local stakeholders to learn about design, as well as revisiting the deep roots, principles and practices of design for transforming territories is compulsory to build effective systemic changes toward circularity.

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Circular Economy Business Strategies - A mixed methods analysis of 131 case studies

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Abstract

The concept of circular economy has gained momentum in the political, scientific and economic debate in the last years as a means to promote more sustainable production and consumption patterns in a growing economy. With the Circular Economy Package, the European Union has released an ambitious program that aims at guiding the European economy towards a more circular economic system. However, concerns are raised that circularity in itself does not guarantee sustainable outcomes, thereby creating a need for a fact-based approach towards circularity and its consequences on the economic system as well as its environmental and social impacts. To better understand company behavior when approaching circularity on different levels and across sectors, in this work 131 projects from the Circular Economy Industry Platform are evaluated regarding their contribution to circular economy from both, a scientific and political perspective. Therefore, a mixed-methods approach was chosen. Content analysis was used to derive qualitative and quantitative information from company statements on the platform. Subsequently, correspondence analysis was applied to find out how previously defined enablers correlate circular economy principles in the sample business applications. This was supplemented by qualitative, semi-structured interviews with company representatives on selected projects. Keeping this in mind, results showed a diverse approach to circularity across the sample projects, thereby partly expanding the sectoral focus of the circular economy package. Furthermore, eco-design, eco-innovation and business models acted as strong enablers for circular actions in the sample, which reflects respective EU policies. At the same time sample projects heavily rely on recycling while missing out on potentially more efficient circular principles, such as reduce or reuse. High diversity was found regarding the evaluation of overall environmental impacts, with some projects providing purely qualitative assessment, while other projects presented elaborated quantitative environmental evaluation including significant positive impact potential. Regulatory issues were specifically found for sound circularity quotas and targets, regarding definitory ambiguities, as well as around resolving issues due to unknown material compositions impeding recirculation. This research indicates, that the proposed systemic transition to a more circular economy has not yet fully entered decision-making processes when companies consider circular economy projects, circular economy projects are mostly minor and or incremental interventions. At the same time, a need for thorough quantification of environmental impacts of circular economy projects to ensure the desired effects and to prevent a circular economy rebound, as well as a vigorous tackling of legislative barriers are encouraged.

Keywords: Circular Economy, Business Strategies, Environmental Sustainability, Correspondence Analysis, Content Analysis

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1. Introduction

As part of the economic transition towards more sustainable production procedures in line with the United Nation's (UN) Sustainable Development Goals (SDGs) and the corresponding Agenda 2030 (United Nations, 2015), and as a response to resource scarcity and difficulties associated with resource intensive economies, the European Union (EU) has - among other policy papers - developed the Circular Economy Package (CEP) (European Commission, 2015). This package aims at guiding "[t]he transition to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized" (European Commission, 2015, p. 2). The most prominent benefit expected from a circular economy is the possibility of decoupling resource consumption and economic growth in respective systems (Ghisellini et al., 2016). This promise is of vital importance to the EU, for through the promotion of circular economy (CE), it can simultaneously promote innovation, economic growth and job creation while also supporting more sustainable production patterns. The CEP is thusly foreseen to significantly contribute to the SDGs, namely goal twelve on sustainable consumption and production patterns. In order to foster economic benefits within the EU, it is desired that resources do not leave the EU boundaries. That is, all recycling and production activities correlating with CE should take place in EU member states, which is suggested to make the circular EU economy in itself more self-sustaining and less dependent on international trade, e.g. regarding conflict minerals or critical raw materials (Genovese et al., 2017; Gregson et al., 2015).

In the CEP context, platforms like the Circular Economy Industry Platform (CEIP) showcase initiatives and projects of European companies contributing to the implementation of circular approaches. The presented projects are a cross-section through efforts of European industries to contribute to circular economy thinking within the EU and cover a wide range of industry approaches towards CE, from specific projects in companies to projects smaller in scale but including innovative business models or an overall reconsideration of entire companies dedicated to circular economy models.

However, scientists raised concerns regarding the European CE strategy for failing to address scientific facts and knowledge. According to them, this can lead to deficient assumptions, strategies, and ultimately, deficient results. Furthermore, concerns were raised that scientific knowledge is not yet developed sufficiently when addressing net impacts of CE processes (de Man & Friege, 2016; Geissdoerfer et al., 2017; Gregson et al., 2015; Korhonen et al., 2018). Hence, the assumption of circular production methods and waste prevention as being the more sustainable option from all perspectives at all times, especially when being linked to SDG twelve has to be reconsidered from a scientific and fact-based perspective.

Therefore, this study aims at evaluating business approaches to CE

i. from a political point of view and how political barriers impede circular efforts

ii. regarding their idea of circular economy

iii. regarding their own impact definition.

To do so, this paper is structured as follows. Chapter 2 describes and explains the methods used for the analysis of the case studies. Chapter 3 presents the results of the studies, including CE approaches and measurement within

the cases, as well as regulatory challenges. Chapter 4 subsequently discusses and concludes this paper whilst including limitations.

2. Methods

In this research a mix of correspondence analysis, content analysis, and qualitative, semi-structured interviews was used for analyzing the sample projects. Altogether, 131 projects from the CEIP were screened and assigned to circular strategies. Furthermore, five sample projects were chosen due to their horizontal and vertical impact potential and subsequently analyzed in more detail using semi-structured interviews for acquiring case-specific in-depth knowledge.

Data sampling

In a first step, all projects committed and published on the CEIP were chosen for analysis. Subsequently, the projects were analyzed and assigned according to different categories, namely CE principles, CE enablers, and CE assessment (for the specific enablers, principles, and assessment categorization, refer to chapter 3). Sectors, as well as barriers were assigned by the CEIP beforehand. Multiple assignments were possible (that is, a project could for example follow various CE principles). To ensure consistent rating, a single researcher was responsible for the assignment process based on project and impact descriptions as well as secondary data obtained from the internet. However, the classification was not double-checked with a second researcher. Consequently, subjectivity on the ratings cannot be fully excluded, since another researcher might have chosen differently when classifying the projects.

Data analysis – Correspondence analysis

Correspondence analysis (CA) is a multivariate statistical method for analyzing cross-tabular data. The method dates back to Hirschfeld (1935) and found wider application after advancements by authors such as Hill, 1974), Benzécri (1979) and Greenacre (2007). CA is a dimension reduction technique that can be applied to nominal data and, thus, is closely related to multi-dimensional scaling and factor analysis for ordinal and metric data (Backhaus et al., 2015). In fact, CA is a particular case of a weighted principal components analysis (Greenacre, 2011). In a CA, a low dimensional solution (in this study, a two-dimensional) is obtained by determining the closest plane to a set of multidimensional points in terms of weighted least-squares (for more details on the theory refer to Greenacre (2011)). In this paper, the method was applied to a matrix linking several 'characteristics' (that is, CE principles and CE enablers) of projects. The result of the correspondence analysis was visualized in a biplot, in which all datapoints are projected onto a joint two-dimensional space. In such a CA biplot the scalar products between the row and column vectors approximate the values in the underlying matrix as closely as possible (Greenacre, 2007). In the study at hand, the CA was performed in R version 3.5.1 (R Core Team, 2018) using the package factoMineR (Lê et al., 2008).

Data analysis – semi-structured interviews and content analysis

Complementary to the correspondence analysis, and to add a qualitative dimension, content analysis was performed comprising an inductive and a deductive part (Krippendorf, 2004). Deduction was used to

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systematically analyze the data regarding the CE enablers and principles, as well as the assessment methods (Mayring, 2015). An inductive approach complemented the data analysis. During the inductive analysis, the interview transcripts and the data on the CEIP were screened and clustered according to emerging topics mainly regarding regulatory challenges. Afterwards, relevant information was extracted, and findings were compiled.

3. Results and Discussion

Taking the 25th of June 2018 as cut-off date, in total 131 projects or companies are presented in the Circular Economy Industry Platform (CEIP). Project descriptions are divided into up to five categories: (i) description, (ii) added value, (iii) challenges, (iv) partners, and (v) contact. For the analysis of the projects, mainly the first three categories were utilized. For specific cases (e.g. for resolving uncertainties), further research in company-related websites or documents, but also in scientific literature, was undertaken. The analysis and evaluation of the projects is structured into two parts. In the first part, general and descriptive results are presented, as well as results from the qualitative content analysis and the interviews. Those include results regarding CE characteristics, self- assessment, and regulatory challenges. The results regarding the CE characteristics (in this research enablers and principles) provide background for the second part, the correspondence analysis.

Sectors

The results of the analysis of the sample projects can be seen in Figure 1 a-d. A division of the sample projects according to sectors can be found in Figure 1a. Unsurprisingly, waste management is the sector with most projects on the platform. Furthermore, the textile sector is represented heavily, as well as plastics and chemicals. Sectoral division on the project page is somewhat unclear, since some sectors might as well be subsectors of other sectors (e.g. packaging could be a subsector of the plastics and the forest or paper industries). However, it is noticeable, that specifically the textile sector is represented strongly in the sample, whereas it hasn't been identified as major issue in the CEP so far. The other prominent sectors in the sample can either be considered as 'classic' circular economy sectors, for example chemicals and metals, or are part of the CEP's focal areas (such as the forest and plastics industries).

CE enablers

For this research, six CE enablers were chosen to capacitate circular change: (1) business models (BM) (Lewandowski, 2016) as a method to incorporate circularity within business considerations, as well as (2) eco-innovation (EI) and (3) eco-design (ED) (Ghisellini et al., 2016; Preston, 2012) as widely accepted concepts amongst politicians and academics. Next, (4) product-service-systems (PSS) as an important part of the 'leasing' or 'sharing' economy (Hobson & Lynch, 2016) together with (5) collaborative consumption (CC) (Lazarevic & Valve, 2017). Lastly, (6) extended producer responsibility (EPR) (Gu et al., 2017) as an increasingly recognized concept amongst politicians for shifting circular considerations to earlier product life cycle stage.

Figure 1b shows the incorporation of CE enablers in the sample. It can be seen, that some enablers, namely business models, eco-innovation and eco-design were the enablers that most frequently were assigned to the projects. This was to be expected due to the prominence those enablers have gained in the political and scientific discourse. For example, eco-design and eco-innovation are linked with CE through respective policy programs

(European Commission, 2011, 2016b). However, the same can be said for collaborative consumption (European Commission, 2016a), the use of which was observed to be rare. An explanation could be the

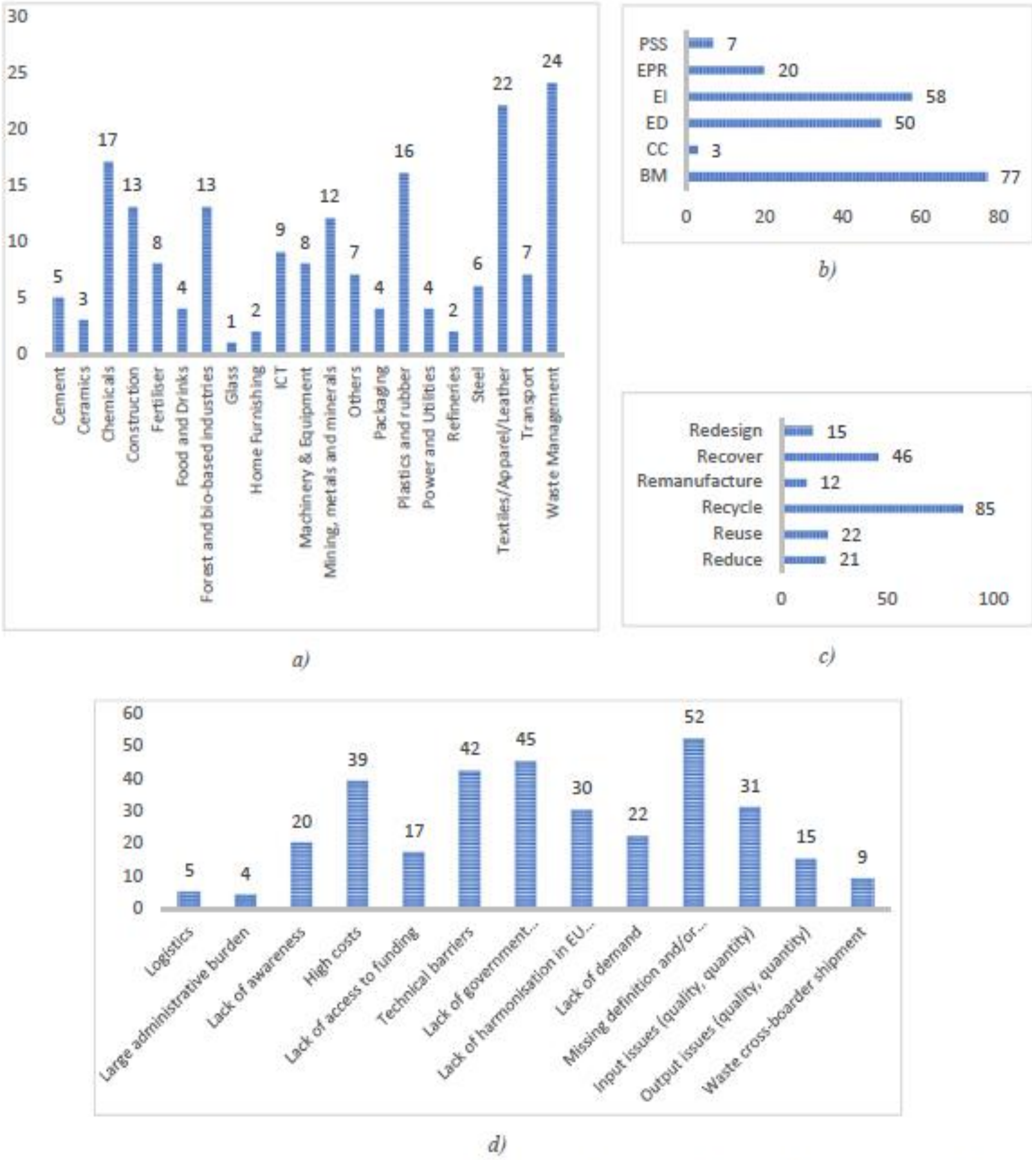

Figure 1: a) sector representation in the sample; b) enablers in the sample (PSS = product-service system, EPR = extended producer responsibility, EI = eco-innovation, ED = eco-design, CC = collaborative consumption, BM = business model); c) principles in the sample; d) barriers to CE in the sample (the abbreviated barriers from left to right are (i) lack of government enforcement and cooperation, (ii) lack of harmonization in EU legislation, and (iii) missing definition and/or standards)

orientation of the sample

towards industrial and manufacturing perspectives, of which collaborative consumption is not an integral part. Also, collaborative consumption is rather perceived as bottom-up enabler, providing opportunities to consumers and entrepreneurs (European Commission, 2016a). The remaining two enablers, product-service systems as well as extended producer responsibility, do not experience a major uptake in the sample.

CE principles

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Parallel to CE enablers, six principles describing CE approaches were chosen for this research. Those include the 3 Rs (Reike et al., 2018) – reduce, reuse, recycle - which are complemented by remanufacture, recover, and redesign (Jawahir & Bradley, 2016). Figure 1c shows that recycling is by far the most frequently applied principle in the sample. This finding is consistent with the popularity of the principle and its easy-to-implement nature in specific sectors (such as steel or aluminum, where recycling has been a mainstream practice for decades due to economic advantages). Furthermore, high concentration of the recycling principle in the sample reflects the political focus – for example, in the CEP (European Commission, 2015), the concept of recycling was mentioned 77 times (followed by reuse and remanufacture with 26 and 19 references, respectively). However, at the same time, recycling is rather seen as a weak circular principle due to many recycling activities being classified as downcycling activities owing to material impurities and / or subsequent low-quality applications (Ghisellini et al., 2016). At the same time, Figure 1c reveals the considerable importance of recovery of different kinds (materials as well as substances) in the sample. This includes mainly other substances or by-products from goods production, which are then used in subsequent production processes and are hence recirculated. Recovery in the sample is closely connected to resource efficiency, especially in production processes. At the same time, recovery of critical raw materials (one the focal areas of the European circular strategy) is not represented.[1] Uptake of the remaining four principles (reuse, reduce, redesign, remanufacture) was less extensive in the sample. Especially reuse, reduce, and redesign are perceived as 'strong' circular economy principles (Geng et al., 2012; Kalmykova et al., 2018; Preston, 2012) requiring more in-depth systemic intervention. Projects using the redesign principle were found to include circularity systemically and partially based their business rationale on circularity. Reduce and reuse on the other hand are the highest principles of the waste hierarchy (European Commission, 2015), and reuse is the essence of 'the power of the inner circles' (Ellen Macarthur Foundation, 2012) and especially linked to dematerialization. However, those principles might also entail controversial aspects for companies (e.g. slowing down industrial production or a possible goal conflict with material recirculation vs. material reduction). Hence, the economic sector might be reluctant to approach circularity from this perspective. Furthermore, diffusion of remanufacturing to other sectors than the traditional ones (such as vehicles and industrial machinery), an aim of the CEP, has not been observed in the sample.

Impact self-assessment and communication within the sample projects

The sample projects were further analyzed according to their environmental self-assessment. In doing so, two layers (qualitative and quantitative) were subdivided in terms of three types of data provision: (1) provision of qualitative data, (2) general provision of quantitative data (e.g. a specific amount of material is remanufactured yearly), and (3) provision of specific quantitative data (e.g. CO_2 eq. emission savings – comparable to LCA midpoint indicators). Furthermore, the three sustainability pillars (social, economic, environmental) were included. Projects could be assigned to more than one category and data provision level. The results are depicted in Figure 2, including a further layer on categories of environmental and specific quantitative self-assessment. Data for Figure 2 was solely extracted from the CEIP. Consequently, even if

[1] Critical raw materials in general were a fringe area in the sample, despite being treated as focal area in the CEP

companies conducted detailed environmental assessments without mentioning this on the platform, this information was not accounted for. Even though it was assumed that environmental added values – if calculated – would be communicated by the company officials, this is a possible source for inconsistencies.

Figure 2 shows, that the majority of projects provided environmental data (only six projects did not), and around 35% also provided specific quantitative data. Social and economic data were represented to a lower extend and to a similar degree. Qualitative data provision dominates in both cases.

Social and economic aspects: (Local) job creation was by far the most popular indicator used. Merely some projects communicated other social benefits, such as health issues or citizen engagement. For job creation, direct and in some cases indirect job creation (potential) was used, ranging from statements such as "creating local employment opportunities" to absolute number of created jobs. While the focus on job creation is in line with the European commission's social focus in the CEP and in scientific literature (see for example Valenzuela-Venegas et al., 2016), the narrow focus on job creation when assessing social impacts has been criticized recently (Pauliuk, 2018).

For economic benefits, a wider range of added values was connected. Most commonly, savings or increased revenues were mentioned, partly alongside with figures. Alongside those financial benefits, 'softer' economic factors played a role. For example, benefits in environmental reporting due to eradication of waste figures or improved marketability ("added branding values") are added values communicated by the companies in the sample.

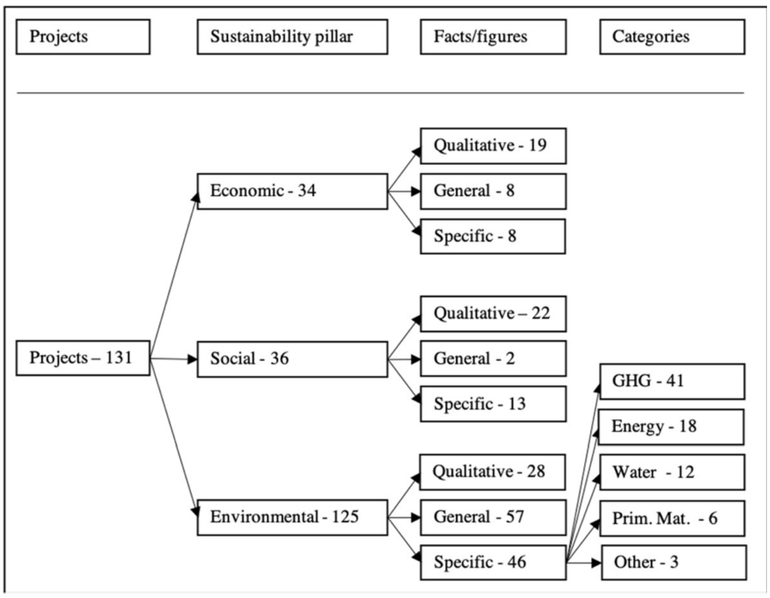

Figure 2: impact self-assessment in the sample; the numbers in the boxes indicate the absolute number of projects providing the respective data

Environmental aspects: The biggest focus in the sample were environmental aspects. Out of 125 projects covering those, 28 (around 22%) did so on a purely qualitative basis. This may be due to (i) high costs for third-party environmental assessment or (ii) the application of qualitative guidelines or policy recommendations (such as best practices or the waste hierarchy). It has been reported that qualitative assessment is common practice among

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companies (Veleva et al., 2017). However, it was argued, that by following such guidelines without case-specific assessments, trade-offs or alternative scenarios may not be assessed appropriately and improvement options may stay unrealized (Geissdoerfer et al., 2017; Saidani et al., 2017). On the other hand, general quantitative data (which can partly be considered as data provided by MFA or resource efficiency metrics, or as input data for LCA) was the most popular way to communicate environmental benefits in the sample (around 46% did so). Here, in line with the EU's focus on resource efficiency, data on material savings, recycled material use over time or recycled content determine those added value sections.

Regarding specific environmental data, life cycle related data was used most commonly. The right layer in Figure 2 depicts the categories used by companies in the sample. Unsurprisingly, GHG emissions are dominating this section due to their prominence and importance in the public debate in climate change. Connected to GHG emissions, energy related indicators were communicated by 18 projects. Apart from that, water related indicators (such as the water footprint) and indicators regarding primary materials are mentioned twelve and six times, respectively. Other LCA indicators, such as land use change, eutrophication, etc. were mentioned three times in total. Thus, those indicators are represented only to a marginal extend. To relativize this result, it has to be said, that companies might calculate those indicators but not publish them due to several reasons (for example due to difficulties in describing the indicators to a non-specialist audience or to avoid communicating trade-offs).

Other indicators, such as specific circularity indicators, which have been developed in considerable numbers in recent years (Parchomenko et al., 2019; Saidani et al., 2019) or indicator sets such as the one developed by Pauliuk (2018), played a negligible role in the sample. Diffusion to mainstream industrial practices in the sample was therefore not happening so far, since merely a single project uses an indicator set for assessing circularity and sustainability simultaneously, while no project communicated the use of a specific circularity indicator.

Methodical issues: During the analysis, some methodical issues arouse regarding self-assessment of projects. Two aspects are briefly described in the following section.

(i) Centrality and suitability of CE aspect: A number of projects focused on circular aspects of minor importance with regards to the overall environmental impact of the product.

(ii) The question of system boundaries: transparency in impact calculation was – also after researching – partly not given (especially when impact assessment was done in-house). Consequently, central questions for circular assessments, such as system boundary setting, trade-offs, or potential rebound effects, remained unaddressed and in the worst case could lead to misleading figures regarding e.g. emission savings. Those issues have been mentioned before by other scholars (Kjaer et al., 2016; Peters, 2016), but remain unresolved in the sample for sustainability and circular assessment.

Regulatory challenges as mentioned in the sample

When submitting projects to the database, companies had the opportunity to describe challenges they faced with regards to circular efforts. Those challenges were subsequently categorized into thirteen categories, ranging from logistics to regulatory issues, financial issues, and demand issues. The categories were defined on behalf of the Circular Economy Industry Platform (CEIP) and can be seen in Figure 1d, where a focus on regulatory barriers, followed by cost issues is observed. For this research, the most important regulatory challenges mentioned in the sample are analyzed. This focus was set due to the political focus of the CEIP, and the evaluation of the projects

with regards to the EU's circular economy package. Table 1 shows the three most common regulatory barriers amon the 131 sample projects: (i) missing definitions and/or standards, (ii) lack of government enforcement and cooperation, as well as (iii) lack of harmonization in EU legislation. Within those, three central aspects were identified: First, transparency issues (for example regarding material compositions of downstream production processes) are central to increase knowledge and to enable recycling efforts across companies and supply chains. Second, definitional issues are – according to companies – a hindrance for increasing circularity. Depending on a materials' definition, it can be used as input for further production processes or not. Particularly central are here the debates around classifying materials as by-products (instead of waste), or how materials can reach the end-of- waste status (and if such a status makes even sense). Other challenges, such as waste cross-border shipment, show a close connection to this barrier. Third, some projects mentioned a lack of quotas as disincentive for industries towards more circular practices. Especially the lack of other than recycling quotas (such as remanufacturing targets) were mentioned. For example, two companies remanufacturing waste electric and electronic equipment referenced regional remanufacturing quotas already in place.

Table 1: regulatory challenges as mentioned in the sample

Barrier (# projects)	Sectors (# projects)	Specification
Missing definitions and/or standards (52)	Chemicals (10); Plastics and rubber (8); Waste management (8)	- Definitional issues (waste, by-products, SRMs) impede recirculation - Cross-border shipment (e.g. difficulties to import remanufactured spare parts) - Missing legislative inclusion of gas recovery and lacking access to funding - Call for more standardised product declarations for more security regarding material composition (relevant for recirculation) - Stronger standardisation of legal perspective and assessment
Lack of government enforcement and cooperation (45)	*Absolute:* Textiles (13); Chemicals (7); Waste management (7) *Relative:* Cement (4 of 5); Steel (4 of 6)	- Demand for stronger government and EU actions to push textile companies towards circular practices - Incentives to support expensive recycling activities - Lack of willingness of national or regional governments to enforce EU legislation - Recognition of environmental performance in Green Public Procurement
Lack of harmoni-zation in EU legislation (30)	Forest and bio-based industries (6); Plastics and rubber (5); ICT (5)	- EU WEEE directive lacks support of other principles than recycling → such targets can be found in Spain and the Belgian region of Flanders - European measures decreasing landfilling of cartridges demanded

In general, CE is considered to be in the phase of organizational implementation (Reike et al., 2018). At the same time, public interest in related issues (or at least sub-issues) is increasing (Chertow, 2008; Lacy & Rutqvist, 2015). Consequently, the momentum for implementing circularity regulations is given. The inclusion of the diversity of circularity is thereby a central issue. Rudiments exist already: spreading remanufacturing across sectors, restrictions to material use (European Commision, 2018), and innovative funding schemes.

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However, those ideas have not led to a comprehensive regulatory framework yet.

Correspondence analysis

Following the semi-structured interviews and the content analysis, a correspondence analysis was carried out to visualize and interpret the correlations between some CE elements. Thereby, the elements of principles and enablers were chosen. Other possible variables, such as regulatory challenges or sectors are subject to further research. For the analysis, a bidimensional plot was chosen. From the axes' labels in Figure 5, it can be seen that around 89,4% of the total inertia is explained through the two dimensions shown in the graph. The remaining 10,6% are partitioned among three more dimensions, making a total of five dimensions for explaining the total inertia. As none of the remaining dimensions has a contribution larger than the average eigenvalue of 20 %[2], a sufficient explanatory value is included in the first two dimensions (Bendixen, 1995).

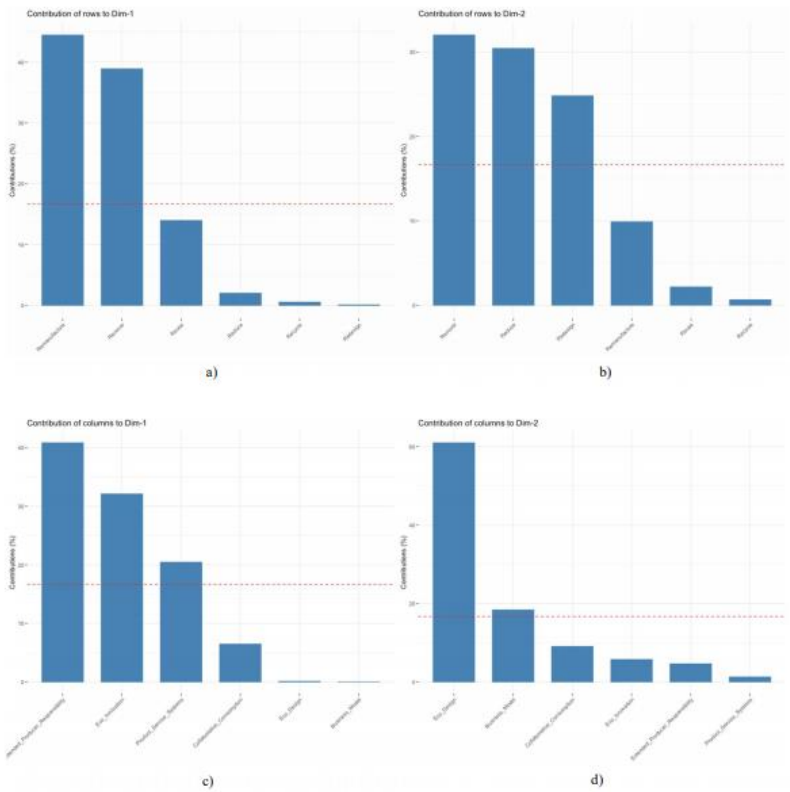

Figure 3: a) contribution of principles to dimension 1; b) contribution of principles to dimension 2; c) contribution of enablers to dimension 1; d) contribution of enablers to dimension 2

The correspondence analysis is depicted in Figure 5, while Figure 3 shows, how the principles and enablers contribute to the build-up of the dimensions of the correspondence analysis. Dim-1 thereby represents the first (that is, the horizontal) dimension, while Dim-2 represents the second (that is, the vertical) dimension. Additionally, Figure 4 shows how well the respective principles and enablers are represented by the first two dimensions.

[2] The average eigenvalue is the same for the rows and columns, as the CE enablers and principles are cross-tabulated in a 6 x 6 matrix.

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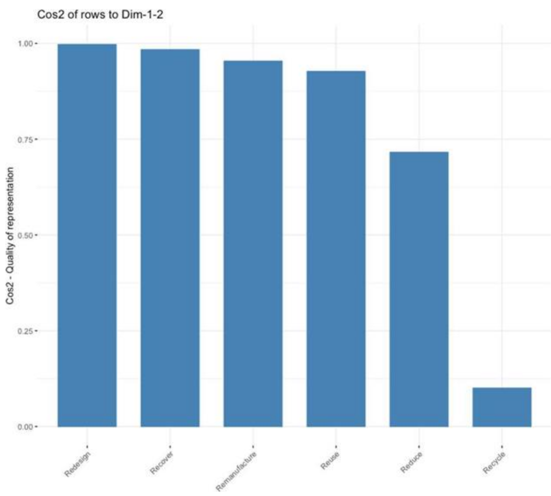
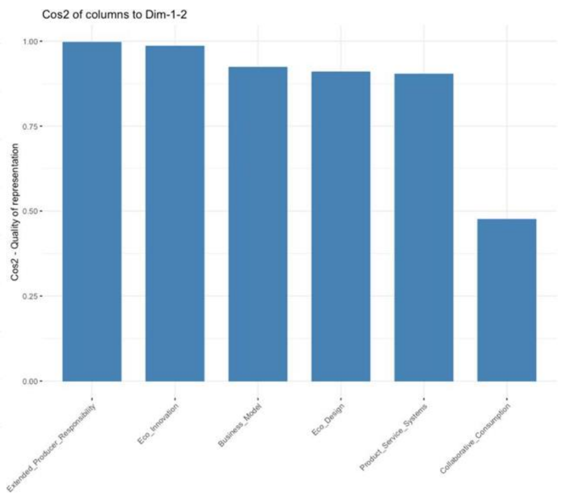
Regarding principles, the first dimension is mainly defined by remanufacture and recover (they have the most influence on the horizontal axis), contributing around 44% and 39%, respectively (Figure 3a)3. Furthermore, three enablers define the horizontal dimension: extended producer responsibility (around 41%), eco-innovation (around 32%), and product-service systems (around 20%) (Figure 3c). Business models and eco-design are basically absent in the definition of this dimension.

The second dimension (represented by the vertical axis) is defined by three principles: recover (around 32%), followed by redesign and reduce (around 30% and 25% contribution, respectively) (Figure 3b). Despite its high significance in the sample projects, recycling is not defining any of the first two dimensions (accounts for less than 1% for each of them). This is because of the universal use of the principle across projects and the connection of recycling to the other principles and enablers, making the principle not discriminating. Regarding enablers, eco-design outstandingly defines the second dimension (around 61%), followed by business models (18%) (Figure 3c). This shows, that for this dimension, it is mainly decisive if a connection to eco-design is observable or not.

All principles except recycling are represented to a value of at least 0.7 (maximum value = 1) within the first two dimensions (Figure 4a). For recycling, the third dimension is crucial (defines the third dimension to 47% and is





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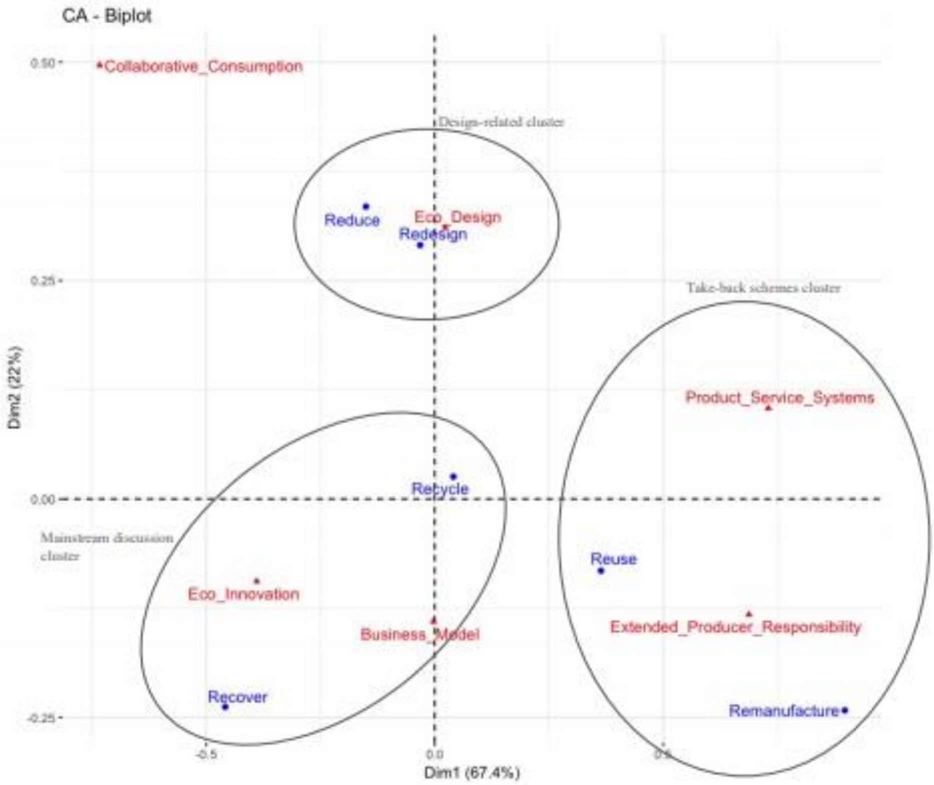

Figure 5: Correspondence analysis enablers and principles - biplot

represented to 0.89). For the enablers, all except collaborative consumption are at least represented to a value of 0.9 (Figure 4b). As for recycling, collaborative consumption is mainly represented by dimension 3 (value = 0.52), which it is also defining for enablers (72%). However, both recycling and collaborative consumption, are not decisive for defining the overall inertia of the plot (due to the low frequency of collaborative consumption and due to the universal use of recycling), which is reflected by the overall explanatory content of the third dimension (>9% of the total variance). Consequently, the low level of representation of both is acceptable. In Figure 5 it can be seen if the enablers and principles are close to each other or if they differ. This is measured according to the relative similarities between the principles. Put differently, if principles are likely to be connected to the same enabler, they are closer together[4] . For example, in the first dimension, remanufacture and recover are negatively correlated, while product-service systems and extended producer responsibility are positively correlated and at the same time negatively correlated to eco-innovation. For the second dimension, recover is negatively correlated to reduce and redesign (for the principles), and business models (and to a certain extend extended producer responsibility) oppose eco-design. Collaborative consumption has highly discriminating attributes, meaning that it relatively strongly pulls correlated elements in its direction. This is due to the fact, that the low absolute number of collaborative consumption projects are correlated with similar CE principles, hence yielding high relative correlations, which the correspondence analysis is based on.

The distances between enablers and principles can't be interpreted beyond general statements (that is, no

[4] The interpretation of inter-distance relationship is only possible within the same group

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conclusion regarding absolute proximity can be drawn). General conclusions, however, are possible. In the analysis, three clusters have been identified: - the design-related cluster, which shows that reduce and redesign are strongly connected, and that they together are related to eco-design - the take-back scheme cluster, where reuse and remanufacture (in the literature, remanufacture is sometimes subsumed under reuse) do more often correlate with PSS and EPR (that is, enablers, where the producer takes the responsibility for a product after its use phase - the mainstream discussion cluster, where the principles of recover and recycling and the enablers of ecoinnovation and business models are located The clusters are not mutually exclusive. Rather, they are to be seen as overlapping and dependent. For example, while the design-related cluster seems very dense and zoned, in fact redesign also shows a strong link to business models: around 73 % of the projects with the attribute redesign also carry the attribute business model. However, the link to eco-design is even stronger (around 93%), and since eco-design is highly influential on the second dimension, the variables are plotted close to each other. It is noticeable, that the design cluster is not tightly connected to the take-back scheme cluster, even though this has been suggested in literature (Bocken et al., 2016; Tukker, 2015), for example through system design for product-service systems or concepts such as design for remanufacturing or design for disassembly, etc. While research in this topic mainly addresses the transmission of those elements to new sectors and businesses, in the sample the established remanufacturing sectors dominate. This also explains the position of remanufacture within the plot, being more tightly connected to business models than to eco-design in the second dimension. Thus, no (re-) design (of systems or products) is necessary. Furthermore, the connection to business models shows, that companies – when introducing remanufacturing projects – do this as a business case. However, the adoption of new take-back schemes faces high business risk, since “important business model hypotheses predict the state of affairs farther into the future” (Linder & Williander, 2017, p. 190). Minimizing this risk could hence increase dissemination of such projects. At the same time, the mainstream discussion cluster connects to the narrative of the CEP, connecting circularity with economic value, of which innovation is an integral part (European Commission, 2015), even though the type of innovation (e.g. incremental or radical) is crucial (Homrich et al., 2018; Tukker, 2015). In the sample, it can be seen, that innovation is rather connected to incremental, technological innovation (e.g. to improve efficiencies in production processes).

4. Conclusions

This research has revealed through semi-structured interviews and content analysis, that within the studied sample of 131 Circular Economy related projects showcased on the Circular Economy Industry Platform, recycling and recover are the most popular CE principles, while it is also those principles, that are considered as ‘weaker’ for achieving a circular economy. At the same time, it has been found, that apparently no uniform or standardized impact assessment method is used, leading to partly blurry or qualitative statements regarding (sustainability) impact potential of CE projects. Thereby, job creation (whether realized or potential) was the most popular social indicator, while environmental added value was predominantly defined in CO_2 eq. emission (savings). Furthermore, companies face various challenges when implementing circularity, whereby ‘missing definitions and/or standards’, ‘lack of government enforcement and cooperation’, and ‘lack of harmonization in EU legislation’ were the most important regulatory challenges. Subsequent correspondence analysis displayed how the previously defined CE principles and enablers are connected and support or oppose each

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other. The analysis can be taken as approximation for policies to directly address intended CE principles and/or enablers. For example, supporting the take-back-schemes of different kinds could lead to diffusion and increased appliance of the remanufacturing and reuse principles. Apart from that, guidelines or directives targeting at (systems) design could lead to application of the redesign and reduce principles. A holistic approach furthermore includes addressing monitoring systems (in this research on product and company level) to eradicate methodical issues such as system boundaries in CE assessment.

This research is subject to several limitations: First, the number of cases is rather small with regards to its heterogeneity. The sample includes projects from 20 different sectors (plus 'Others'), as well as projects discussing single processes to projects, where circularity is introduced on a company level as business rational. While this reflects the versatility of CE, it complicates comparability of the projects, and impedes generalization of the results. Second, a single coder was responsible for assigning the CE elements (enablers and principles) to the projects. Subjectivity can hence not be fully excluded, since another coder could have chosen differently. In order to overcome these limitations and to expand and build on this study, further research could be directed to including a larger sample in the analysis or towards analysis for specific sectors or company levels. Furthermore, to increase understanding of the regulatory actions, an extension of the correspondence analysis towards inclusion of regulatory barriers is encouraged. Additionally, the inclusion of sectors in the correspondence analysis could be subject to further research.

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Innovative approaches in education for sustainable development

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Developing graduates with capabilities in complex problem-solving for the 21st Century

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Abstract

The United Nations Sustainable Development Goals (UNSDGs) are challenging decision-makers to think beyond conventional methodologies and materials, and models for development. Higher Education Institutions, particularly in engineering and built environment studies, have identified that students want 'to make a difference'. However, there are significant challenges in embedding improved problem-solving within curriculum that builds capacity for students to undertake complex, system thinking and address unconscious-bias. This leads to the lived reality of programs that are for the most-part unchanged in their content and approach, with short-falls in graduate capabilities to fulfil on the aspirations of agendas such as the UNSDGs.

This paper draws on the lived experiences of the authors in the geospatial industry, and piloting coursework and student engagement with a collaborating research partner in Nagoya, Japan. Specifically, the authors present findings from two years of enquiry into transforming student perspectives on their discipline and career opportunities, through an international collaboration between an Australian and Japanese University. The authors present the model as a narrative for framing their appreciation of professional practice and career planning. The research approach to sensemaking consists of surveys, focus groups and mind-map comparisons at the commencement and conclusion of the studies. The findings provide rich insights on student experience on this transformative 'look to the horizon' experience, through a focus on one of the most densely populated regions of the world, on the central East Coast of Japan. Through a ten-day field trip to Nagoya and Tokyo, students visit sites including manufacturing, transportation, energy, retail, residential and academic facilities, considering each through the lens of the CDIO process (i.e. Conceive, Design, Implement, Operate) and lessons learned regarding future optimisation. Within this context, this paper introduces the potential for Cynefin theory to help understand why education for sustainable development is so challenging, through considering the differences between simple, complicated, complex and chaotic problems and their implications for learning design.

The research findings provide evidence of this learning experience transforming the thinking of early program students as they were able to immerse in real world examples are engineering solutions related to disaster management, resilience and adaptation. The findings also provide a reference point for embedding sustainability into engineering education, assisting colleagues globally in preparing the future workforce with the ability to look at global problems and develop context-specific, technically sound engineering solutions using their the 'hands- on', 'on-the-job' business skills. The study has immediate implications for embedding the UNSDGs within coursework across built environment programs, wherein the authors propose the criticality of enabling students with an appreciation of the importance of appreciating complexity and addressing unconscious bias, providing a robust scaffold to use their discipline skills to problem-solve.

Keywords: Higher Education Institutions, Sustainable Development, Curriculum, Immersive Experience,

Cynefin Theory

1. Introduction

In mainstream literature the often-cited world view is that by 2050 more than half of the world's population will live in 'mega-cities' comprising more than 10 million people, with a substantial proportion of this urban migration occurring in Asia (Okazawa & Murakami, 2019; Smith & Hargroves, 2005; Smith, Hargroves, & Desha, 2010). Such statements are then often followed by urgent calls-to-action regarding the priority problem to be solved, namely to create or redesign cities to accommodate this end state. However, connecting this decision on how to act with just one predicted population distribution scenario has limiting implications. For example, it limits being able to plan for the complexity of global population mobility, where a range of scenarios relating to sea level rise, extreme weather patterns, tectonic movements and pollution could result in different configurations of humanity around the planet. It also limits the exploration of other potential pathways for enabling the 'quality of life' for a steady-state global population of around 10-12 billion people and environmental stewardship towards sustainable development outcomes that decouple economic growth from environmental pressures (Smith et al., 2010).

The United Nations Sustainable Development Goals (UNSDGs, 2015) is challenging decision-makers to think beyond conventional methodologies and materials, and models for development. Within the engineering profession there are calls to take a holistic and inclusive approach to design (Vemury, Heidrich, Thorpe, & Crosbie, 2018), and to become aware of our own unconscious biases in designing 'solutions' for the diversity of challenges present in the 21st Century (Kirman, Simon, & Hays, 2019; Mohsen, Ismail, Parsaei, & Karwowski, 2019). In The Necessary Revolution (Senge, Smith, Kruschwitz, Laur, & Schley, 2008) and The Fifth Discipline, the authors present the critical need for 21st Century professions to appreciate what it means to live and work within a system-based appreciation of available resources, and an age of uncertainty, where past experiences - for example with climate - do not provide a reliable indication of future events and outcomes. Alongside such efforts, several seminal authors in decision-making warn of the limits of current thinking in a world that is information- rich yet knowledge-poor. In The Impact of the Highly Improbable (Taleb & Swan, 2008) and Antifragility (Taleb, 2012), the authors articulate the problems with making decisions in a vacuum of meaningful data on the range of risks and scenarios. Rosling, Rosling, and Ronnlund (2018) describe the severe lack of common knowledge regarding population demographics, culture, needs and desires, and the need for humanity to practice 'factfulness' towards making better decisions for planet and for humanity. Robson (2019) defines the 'Intelligence Trap', where intellectually intelligent and 'well trained' professionals can make decisions that are sub-optimal, if actual facts, contextual factors and unconscious biases are not addressed.

Fortunately, literature from the educational and psychology fields provide well-established guidance and support for engaging with current context, dealing with unconscious bias, failure and for making better decisions. Snowden uses the Cynefin Model to propose that 21st Century problem-solving requires practitioners who can distinguish between simple, complicated, complex and chaotic environments, and then to act accordingly (Snowden, 2000). Syed (2015) discusses avenues for enabling a culture that embraces risk and failure, and in Nudge, Thaler & Sunstein (2009) raise questions about the rationality of many judgments

and decisions that people make, with predictable mistakes arising because of heuristics, fallacies, and the influences of social interactions. In Thinking, Fast and Slow, Nobel Laurette Kahneman explains the necessity

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of spending time 'thinking slow' to problem-solve effectively, creating time to do this up-front distinguishing before embarking on a course of action (Kahneman, 2011). Unfortunately, such thinking and systematic exploration of decision-making

is not our natural tendency or desire, requiring shifts in behaviour to achieve. From childhood through to adulthood, it is essential to educate, train and remind ourselves of the fallibility of decisions, towards problem-solving that is accountable and defensible.

In the education sector, higher education provides an important pathway for developing critical thinking skills, building on secondary school experiences across a breadth of topic areas, to enquire into particular professional discipline contexts. Curriculum for professional specialisations such as engineering, design, planning and law have highly regulated curriculum that is often governed by external accreditation agencies (Desha, 2013). However, these are increasingly 'outcomes focused' rather than prescriptive, enabling consideration of different learning and teaching strategies to produce professionals who are cognizant of current reality, and who can think (Engineers Australia, 2011; Byrne, Desha, Fitzpatrick, & "Charlie" Hargroves, 2013; King, 2008). Furthermore international agencies are advocating progressive thinking to address 21st Century challenges, including for example the International Engineering Alliance (2019), and the World Federation of Engineering Organisations (2018). Within this context, a key challenge for educators is to first enable students to understand their contribution to reinforcing sub-optimal decision-making, and then to develop their capacity to contribute to designing and implementing robust evidence-based solutions – and faster than conventionally achieved, acknowledging the time-lag dilemma facing the higher education sector (Desha, Hargroves, & Smith, 2009). The challenge is twofold: firstly, the challenge of developing the ability to accurately distinguish context – the facts and trends – and secondly to distinguish perspective – the priority actions to take, as acknowledged in inclusive engineering (Alpay, Ahearn, Graham, & Bull, 2008; Jolly, Crosthwaite, Brodie, Kavanagh, and Buys, 2011), in intercultural competency (Goldfinch et al., 2012), first year curriculum (Crosthwaite & Kavanagh, 2012), and in education for sustainable development (Mulder, Desha, & Hargroves, 2013). Addressing this requires deliberate educational approaches to expand student capabilities in non-binary, circular thinking and problem-solving. It also requires gathering data to evaluate the success of developing such capabilities, through designing insightful assessment and evaluation.

In this paper, the authors present the ethnographic journey in exploring ways to cultivate a workforce that is capable of moving beyond these limiting design constraints towards complex problem-solving in the face of increasing expectations for rapid response. This has involved the first author, with the tutor assistance of the second author and advice from the third-author, running an international initiative that attempted to apply the above insights into a transformative experience for undergraduate engineering students. The authors were motivated to design a professional-behaviour intervention course "2007ENG International Engineering Practice" as to Japan (Nagoya) for undergraduate engineering students that aspired to shift attitudes on context and perspectives about the role of engineering for 21st Century society. The first author was keen to know whether Japan would be a good case study to provide students with a shift in appreciation of context and perspective, with areas of very high-density populations such as Tokyo and Osaka, interspersed with very low-density village living. Within the Asia-Pacific Region, there are many significant engineering lessons to be learned from Japan, spanning the last 200 years since the industrial revolution and including the country's recent experiences in responding to and recovering from with the Great Eastern Japanese Earthquake, and preparations for the impending catastrophic Nankai earthquake. In addition, the first author is fluent in Japanese and Japan has the benefit of being within an eight-hour flight from Australia.

The paper outlines the experiences and evaluation findings from two years of implementation and maps the insights to existing literature that might help to explain the observations. Specifically, the authors consider, how do we embed the Cynefin way into formal education design (learning design), in an education environment where such literature does not necessarily turn up for educators looking for learning design assistance. The paper begins with a description of the initiative, followed by a summary of the research methods and discussion of the evaluation undertaken to date, connecting the findings to literature that discusses and guides interpretation of the experiences. The paper concludes with comments on other data to be gathered to evaluate the progress of the initiative, towards better informed graduates who can apply knowledge and skills in ways that foster improved problem-solving.

2. Description of the Initiative

In this section the authors describe the initial plans for the course, within the journey of developing a program for undergraduate students that could 'jolt' students into appreciating the need for whole-system design and committing to applying this design practice in their subsequent course-work. The initiative augmented an existing relationship between the first author and colleagues at Chubu University, who were working in the core research area of digital earth and green infrastructure exploring decision-making pathways for complex built environment challenges, towards nature loving, nature inspired and place-based solutions. Within this context Griffith University partnered with Chubu University (Nagoya, Japan) through the Institute for Advanced Studies, to create an intensive coursework experience for undergraduate engineering students.

After successfully completing this course it is anticipated that students should be able to describe the range of engineering design challenges and opportunities evident in mega-cities, drawing on the Japanese example; undertake carbon calculations for international travel and develop a strategy for offsetting these emissions; and evaluate the potential for Australian undergraduate engineers to develop capacity to address complex challenges in urban development. Students should become aware of the need to collect better data, organise the data to be meaningful, and to take time to consider the implications of alternative decisions, even if problems or situations appear 'urgent'. Furthermore, the course aims to expose students to similarities and differences in cultural contexts, influencing design constraints, opportunities and end-user dynamics. The course is offered at the end of first year engineering, following students completing: Engineering Materials, Engineering Design Practice, Creative Engineering, Engineering Mathematics 2, Engineering Maths, Numerical and Computing Skills, Engineering Science, Engineering Mechanics (Desha et al, 2019).

The first assessment for this course comprises a carbon offset report, which requires a mind map and analysis of the student's greenhouse gas emissions in preparing for, traveling to and from the field trip, and consideration of offset strategies over a 12-month period to counteract the emissions. The second item is a reflective video/photo presentation, which covers a reflection of the student's experiences in the study tour component of the course. The final item is a technical report, which requires students to reflect on their learning about context and shifts in perspectives about cities of the future, considering the topics addressed during the lectures, workshops and site visits.

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The learning outcomes target context and perspective development (assessment shown in brackets):

1. Ability to describe the range of engineering design challenges and opportunities evident in mega-cities around the planet, referencing Japan (video and essay).
2. Ability to undertake carbon calculations for international travel and develop a strategy for offsetting these emissions (report).
3. Ability to evaluate the potential for Australian undergraduate engineers to develop capacity for working in urban mega-cities, through their engineering program (essay).
4. Ability to communicate the outcomes from the course in a range of ways including oral presentations (video production), and in written form (report and essay).

Current and future challenges and opportunities faced by Japan are highlighted through in-class lectures on innovation, sustainability and resilience. This is intended to provide an insight into the technical, social, environmental and economic issues facing the engineering discipline and the considerations of contextual factors impacting decision making and problem solving in complex environments. It is intended that within this experience the students would better understand the context, which would inform or even shift their perspectives on engineering practice.

3. Research Methods

A qualitative mixed-method evaluation approach was chosen by the authors at the commencement of the journey, comprising an in-country questionnaire and focus group discussion at the end of each in-country experience. Two years of data have been collected to date, with data collection and analysis methods described in the following paragraphs. The student cohort consists of students from a variety of engineering and built environment courses including civil engineering, electronic engineering, electronic and energy engineering, software engineering, environmental engineering, industrial design, urban and environmental planning. The majority of the students stated that it is their first visit to Japan. One student had not previously travelled abroad.

All students participated in the one-hour focus group in the classroom of Chubu University, as two discrete undergraduate cohorts (10 in 2017, comprising 4 females and 6 males, and 9 in 2018 comprising 4 females and 5 males). One focus group was considered appropriate for each cohort, given that the usual male/female biases identified in other studies (Kelley & Bryan, 2018) could be managed by the first-author. Table 1 presents summary pf the participant with the nomenclature used to support the focus group quotes.

The participants considered the following visioning 'blue sky' question*: How has your appreciation of Engineering Practice and International Engineering Practice shifted as a result of what you've experienced in- country?* Within each focus group, students were asked to identify any shift from previous appreciation of the Japanese context, and to reflect on new knowledge and competences gained to solve the problem. The focus groups were predominantly a self-directed process. Participants were encouraged to self-nominate their turn and invited to add additional reflections to build on what others said. To reduce the bias of responses motivated by students wanting to 'fit in', the first-author regularly interjected with counter-comments to those observed by the students and sought student input or thoughts on these comments. Furthermore, students were praised on their willingness to respond, not on what they said.

Table 1*: Summary of the two participant cohorts, their program details and analysis coding*

Year	Gender	Course	Year	Code
2017	Female	Bachelor of Engineering (Civil)	1	S17-1
2017	Female	Bachelor of Engineering (Civil)	1	S17-2
2017	Male	Bachelor of Engineering (Electronic & Energy)	1	S17-3
2017	Male	Bachelor of Engineering (Mechanical)	1	S17-4
2017	Male	Bachelor of Engineering (Software)	1	S17-5
2017	Female	Bachelor of Engineering (Civil)	1	S17-9
2017	Male	Bachelor of Engineering (Civil)	1	S17-10
2017	Male	Bachelor of Engineering (Electronic)	2	S17-7
2017	Male	Bachelor of Engineering (Electronic)	2	S17-8
2017	Female	Master of Environmental Engineering and Pollution Control	2	S17-6
2018	Male	Bachelor of Engineering (Civil)/ Bachelor of Business	1	S18-7
2018	Female	Bachelor of Engineering (Mech)/ Bachelor Industrial Design	2	S18-6
2018	Male	Bachelor of Engineering (Mech)/ Bachelor Industrial Design	2	S18-2
2018	Male	Bachelor of Engineering (Civil)	3	S18-1
2018	Male	Bachelor of Engineering (Civil)	3	S18-3
2018	Male	Bachelor of Engineering (Civil)	3	S18-4
2018	Female	Bachelor of Engineering (Civil)	3	S18-5
2018	Female	Bachelor of Urban and Environmental Planning	4	S18-8
2018	Female	Bachelor of Urban and Environmental Planning	4	S18-9

A survey was administered at the end of each in-country experience on an individual basis. This tool gathers data on student appreciation of the value of the lectures and field trip elements, and cross-checks individual responses generated during the group discussions. Similar methodological approaches have been adopted in previous engineering education research with wider implications on engineering curricula (Byrne et al., 2013). The first in- country survey was undertaken on the last day of the students' time in Japan, online using the SurveyMonkey tool, and consisting of 5-point Likert scale questions in addition to open-ended questions.

An additional survey comprised the evaluation of course experience, administered as an end of trimester survey by the Griffith University central surveying unit. This provides a third-party indication of student appreciation and satisfaction of the course, undertaken in Week 11-12 of the trimester using the Griffith University survey tool. The survey comprised five pre-determined questions (Q1-Q5) in addition to two course-specific questions determined by the first-author.

In order to allow some comparisons to be made, the data was qualitatively analysed using a clustering method constructed from the key facets of the Cynefin framework, to visualise students' understanding of urban planning and design as containing simple, complicated, complex and chaotic components. In the following section the results of the focus groups and surveys are presented and then discussed in relation to the first author's aspirations for the course, mapped to key literature that supports and refutes the findings.

4. Results – Focus Groups

Findings are presented under several themes, including the role of factual and relevant information (context), the role of professional practitioners (context) and the importance of interdisciplinary teams (perspective). 3.1 Role of factual and relevant information (context). More than half of the students in each cohort reflected that opportunities will open up for 21st Century engineering if students develop capacity to "*correctly identify*" (S18-9) problems, and then create "*appropriate*" (S18-8) solutions for the problems. For example, "*I think*

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when I've done a bit of work in property and buildings, I can see that engineering doesn't have to be on the side, be more corporate and what not, understanding that all the work that the professors here, and engineers in different parts of Japan. It highlights the breadth of opportunities in terms of career and impacts you can have, like working on global energy created, or to bring world peace, or advising government, or doing research, or working with NGOs, or working with the UN, lots of different avenues and opportunities, you don't even know what you can do"(S17-10).

Many students noted the shift in their appreciation of the magnitude and significance of infrastructure resilience demonstrated in Japan. For example, "*Japan is an exemplification of the spirit of the SDGs through its resource management, disaster preparation and adaptation to the next stage of human society. From an engineering perspective, there are many challenges to overcome, however Japan presents a bright picture of what the future of the world may one day look like*" (S18-9).

Several students in both cohorts spoke to the importance of "*system things*" (S17-1) and "*ability to deeply understand the interconnections and interrelationship*" (S17-3) with regard to making informed decisions in micro and macro levels. For example, "*The connection between decision-making and implementation has to be there so that you can make good decisions that actually are sustainable and not just in a short-term perspective. And integrating that systems thinking, not just on a project, but on a macro policy and strategy level as well"* (S18-3).

Some students reflected on the difficulty of sense-making regarding the "*Japanese way*" (S18-2) of addressing some humanitarian challenges. For example, "*I really thought since the trip (about) the idea of fatalism that I definitely (see) persist(ing) in Japanese culture. They have this intense reference for spirituality, they take such measures in time to create shrines and go back there. If we knew that some things are going to happen why would they still live there? What else are they going to do? We face a lot of large-scale problems here. Oceans are rising, why aren't we taking measures?*" (S18-2).

4.1 Role of professional practitioners (perspective)

Several students in each cohort reflected on their appreciation of "*unprecedented global challenges*", "*requiring engineering graduate to be upskilled with 21st Century problem-solving*" (S18-7). Students discussed the emotional challenge of seeing the nuclear power plant and then visiting Hiroshima, reflecting "*that was hard*" (S18-1) and "*it was difficult*" (S18-9). They also spoke to feeling inspired to think creatively and apply their knowledge to real contexts. For example, "*Japan is so forward in being proactive, with engineering in every discipline. I think as engineers now our responsibility is to be, after this point, not to be the same. personally at least, I'll be a little more driven because I've seen a little bit more of the context*" (S17-2). In each cohort a student also noted that problem-solving from historic experiences is unlikely to meet expectations on suitable solutions (with much agreement via nodding in both cohorts) (S18-2, S18-9).

Student responses across both the 2017 and 2018 cohorts expressed their shift in appreciating the breadth of the practitioner role in city planning and engineering. For example, "*I think when we went to Hiroshima it made me realize that being an engineer is sort of being like a super power, in the size of the potential reaction and you have to decide what you stand for, what you want to create in this world, who you really are, sort of you are in a position to make whatever you want basically, and that's just remarkable*" (S17-7). Students pointed to improved understanding of phrases such as "*problem identification*" (S18-6), "*problem definition*" (S18-3) and "*assessing the severity to address the global sustainability*" (S17-1). For example, "*I realize that engineering isn't just another job, we actually play an important role in the direction society takes, in doing a job well or doing it badly has ramifications on the future of society*" (S17-5).

In the 2018 cohort, this was further augmented by students' referral to global applications of engineering practice that showed super conductor and the ability to transform the future energy. Several students indicated their shift in understanding regarding improved level of energy storage. For example, "when we were having a lecture about the power lines, it made me realize when they were talking about the almost global power grid, how engineering can be on the forefront of blurring the lines between countries so that each country isn't separated and self- sufficient… it makes the world look more globalized yeah…engineers may be able to do things politicians aren't able to, people like Donald Trump, if you have engineers making the infrastructure like global power grids it really opened my mind" (S17-8).

Some students struggled to understand the pedagogical approach and intended learning outcomes but were beginning to think beyond the conventional program deliverables of theories, equations and calculations, with conscious regard for the thinking process. For example, "*I guess for me – I am a very black and white thinker. And studying engineering we always learn a theory or a concept or how to calculate something in particular and we would work on that perfecting it. And then learn how to apply that in different situations. Being in Japan, I questioned myself where is the theory, where is the concept, what are we learning*?" (S18-5).

4.2 Role of interdisciplinary teams (perspective)

All nineteen students in both cohorts mentioned their shift in appreciating the critical need for interdisciplinary teams collectively working solving problems, although there was limited reflection in what ways this could be possible. For example, "*it's amazing to see how even though environmental engineering and civil are different from each other we can work together in a team. That's been amazing. Actually, Australia has more to benefit and learn from Japan*" (S18-9).

Students of both cohorts also commented repeatedly on their newfound appreciation of links between disciplines like engineering, agriculture and geo-spatial technologies. For example, "*before coming here I kind of had an idea of what software engineers do, but I realize now that I didn't know exactly how they worked and intertwined with the other fields, like civil, etc and also combined with other industries, such as agriculture. It's really interesting. It's always interesting to see how people who work in your future field, in that business, and really get a feel about what it involves. It's good to see that*" (S17-10).

The majority of students in both cohorts were able to speak to the opportunity for them to apply best practices and technologies from Japan to other global contexts if it could be adapted to local conditions. For example, "*And I think there are examples of that here, done well and done poorly, and I think it's important globally to look at those examples, learn lessons and build upon that and not make the same mistakes again*" (S17-3). In particular students commented on their shift in understanding how much of Japan's story could be learned from, relating to innovation in technology, knowledge, and ambition and commitment (S17-6, S18-1, S18-6, S18-7). This extended to students commenting on Japanese companies aligning their practices with UN Sustainable

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Development Goals has inspired the students. For example, "*I now understand the need to learn of different ways of thinking and deciding in order achieve the planning competencies and have a better way of responding to the sustainable development goals. By understanding how Japan responds in the face of great uncertainty, I can now put this theory into practice and work towards succeeding in my field*." (S18-9).

5. Results - Surveys

In addition to the focus group discussion two surveys were used to evaluate the students' perceived satisfaction regarding the value of various components of the field trip, and the course as a whole. As student comments in the open-ended questions were anonymously provided, the quotes are given without direct reference to the individual student.

5.1 Evaluation of in-country lectures and field visits

In total there were 17 respondents, including 9 from 2018 (90 per cent response rate) and 8 respondents from 2017 (72 per cent response rate). Results are discussed in relation to feedback regarding students' satisfaction with the value of the nine in-country lectures, and with the 13 in-country field visits.

5.1.1 In-country lectures

The majority of students reported being satisfied or very satisfied about the lectures delivered during the field trip (Table 2). This was further supported by the open-ended question responses where students provided a number of specific examples on key lectures from the students' perspectives, described below.

Table 2: *Survey results - student satisfaction (Lectures)**

Lecture Description	Not at all	Unsatisfied	Neutral	Satisfied	Very satisfied	Respondents (out of total)
Welcome Speech	1	-	2	8	6	17/19
Introduction	2	-	1	9	5	17/19
Smart and resilient agriculture	1	-	3	5	8	17/19
Waste and Resource Recovery	1	2	5	7	2	17/19
Introduction of Smart Grid System	1	-	2	7	5	15/19
Transportation	2	-	2	5	2	11/19
Health GIS	1	-	2	6	7	16/19
Super Conductors: The future of energy	1	-	2	7	8	18/19
Coastal Cities Resilience	1	-	-	6	9	16/19

* Number of participants who selected that level of satisfaction. Note some students did not respond to some questions "N/a"

The use of multiple pedagogical techniques to offer a meaningful learning experience for students was appreciated through the student comments. For example, "*YouTube videos, simulations, paper handouts which made it feel varied, and when lecturers brought in hands-on stuff to interact with after the lecture (e.g. Prof Ito standards games, Prof Izutsu liquefaction demonstration using the beads & paper model, Prof Fukui UAV). It was also really helpful to have the physical/digital lecture slides afterwards to help us with the pebble pad reflections, save writing in the moment.*" The structure of the content was also commended, "*I think the range of topics covered was extensive and well structured. Especially with solar/nuclear energy being put together with the Hamaoka* power plant visit, the standards lecture close to Eco conference etc. Topics in Digital Earth and the Agriculture IoT talk were particularly interesting to me as a software engineering student". Some students highlighted few obstructions they faced during the lectures which include the clarity and language factors. For example, "There were some slide that had not been translated to English which made it hard to concentrate and know what was going on".

They also highlighted the shift in perspective during this immersive experience, "Being immersed in another culture. Going to a Japanese university and getting lectures from Japanese professors on what they do and research. Meeting other students. Eating different foods and trying everything. Experiencing different events such as the Nabana no Sato or site visits such as the Hamaoka Nuclear Power Plant were very interesting and should be kept as a staple depending on the dynamic of the tour. Meeting other Griffith students who are working for companies in Japan was also insightful."

5.1.2 In-Country field visits

The following figure shows the student satisfaction levels on the field visits made during the in-country intensive. In particular, students were very satisfied with the Toyota manufacturing facility, Hiroshima Peace museum, and the Scmaglev and Railway Park

Table 3: *Survey results - student satisfaction (Field Visits)**

Field Visits	Not at all	Unsatisfied	Neutra l	Satisfied	Very satisfied	Respondents (out of total)
Toyota Manufacturing Plant Tour	1	-	-	1	13	15/19
SCMAGLEV & Railway Park	-	-	2	4	6	12/19
Nagoya Port & Aquarium	-	-	4	5	6	15/19
Nagoya Castle	-	-	5	5	3	13/19
Hamaoka Nuclear Facility	1	2	2	5	5	15/19
Hiroshima Peace Museum	-	-	2	6	7	15/19
Miyajima Island Village and Gates	-	-	-	5	10	15/19
Kyoto (place of choice)	-	-	3	5	9	17/19
Kyobashi Station and Circular Garden	-	-	3	7	1	11/19
Trade Investment Queensland	-	-	2	5	8	15/19
Tokyo Tower	-	-	5	7	3	15/19
EcoProducts Exhibition (Tokyo Big Sight)	-	-	-	3	3	6/19
Shiodome City Centre (Tokyo Lendlease)	-	-	1	3	2	6/19

* Number of participants who selected that level of satisfaction. Some students did not respond to some items, indicated by N/a

While the majority of the student cohort was satisfied or very satisfied with the field trips there were number of students who commented on challenges with the experiences. One student reflected, "*that gave us good background cultural context & experience of engineering practice for all different types of engineering and how they relate together. Well placed with the lecture's topic-wise. Probably the range of areas and things we got to see and experience. Good mix of education and fun, the variety and getting access to some of them such as the*

Hamaoka Nuclear Power Plant is what really made some of them impressive and I think even the revisit value

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is quite high. I would like to go on them again".

Students reflected on their challenges in the open-ended responses as follows, "*For most of them the trouble was insufficient time, but I guess that's just more of a personal issue since I'm a slow guy. For instance, 1h at the Hiroshima peace park was way too little, you barely get to take anything in before you realise you have to go back out. The devastation is just intense, and you shouldn't rush that sort of thing. I almost feel as if it should be made to have just one field trip/site visit a day, two max, as squeezing them all in just takes away most of the individual experience of each and I really felt that was a shame for a lot of them*". Another student commented, "*One thing that was difficult was time. If we could have spent some more time at places would have been nice. Like Hiroshima it would have been nice if we could have spent more time looking at the area. Other than that, it was done well*".

5.2 Evaluation of course experience

In 2017 45.5 per cent of the student cohort responded to the survey while in 2018 this improved to 80 per cent of the student cohort responded to the survey. Results are presented in Table 4 for both cohorts and discussed below.

Table 4: *Survey results - student satisfaction (Field Visits) **

Survey Questions*	Cohort Year	SD (%)	D (%)	N (%)	A (%)	SA (%)	Respondents (out of total)
This course was well-organised	2017	-	-	20	40	40	5/10
	2018	-	-	-	50	50	8/9
The assessment was clear and fair	2017	-	-	-	40	60	5/10
	2018	-	-	50	12.5	37.5	8/9
I received helpful feedback on my assessment work	2017	-	-	-	-	100	5/10
	2018	-	-	12.5	12.5	75	8/9
This course engaged me in learning	2017	-	-	-	40	60	5/10
	2018	-	-	12.5	37.5	50	8/9
The teaching on this course was effective in helping me to learn	2017	-	-	-	-	100	5/10
	2018	-	-	-	37.5	62.5	8/9
Overall I am satisfied with the quality of this course	2017	-	-	-	60	40	5/10
	2018	-	-	-	25	75	8/9
Overall this course was effective in developing my ability to think globally and to consider issues from a variety of perspectives	2017	-	-	-	-	100	5/10
	2018	-	-	-	25	75	8/9

* SA Very Satisfied; A Satisfied; N Neutral; D Dissatisfied; DS Very dissatisfied

In 2017 40 per cent strongly agreed and 60 per cent agreed to the statement of "*Overall I am satisfied with the quality of the course*". In 2018 this improved to 75 per cent strongly agreeing and 25 per cent agreeing to the same statement.

In 2017 students added substantial comments that enabled insights on student engagement and the experience they gained through this course. This included for example one student reflecting, "*The experiential component was the best part- being able to observe and interact (by learning & questioning about) examples of* *engineering in Japan. The activities were spread across all disciplines of engineering and all really interesting and engaging.*

Site visits and lectures relating to other topics e.g. Toyota Factory opened up learning about things I wouldn't have learnt otherwise, and I can see how all the disciplines interact to solve main issues: resilience, sustainable infrastructure, energy, transport etc."

Students also highlighted areas they thought that could be improved. For example, another student reflected, "*Giving the students a better idea of what the trip includes and is about beforehand will definitely help. Itinerary and transport routes (how to get somewhere, where we're staying) will help give a better idea of the trip to students interested or looking into it. The more details early pre-trip information encompasses, the more likely the student can come to a comfortable decision in whether they want to go on the trip and take the course. Also, an intensive Japanese course would be helpful for those wishing to understand the language and not feel so alienated in a foreign country. Simple words/phrases and sentences can go a long way as well as possibly learning Hiragana and Katakana, Kanji would be too much. More importantly though I believe learning Japanese etiquette is more of a priority for those coming into Japan with no experience of the culture.*

Simple things like how the Japanese use escalators, line up for trains, greet each other, and so on. Also help to prepare for the culture shock, show students just how crammed train carriages can be and what to expect when everyone has to get in one. Communication is a big one and getting lost is a no, so letting everyone know which station everyone is stopping at and/or going will help get everyone on the same page in terms of travel".

This comment from the 2017 student cohort was then addressed in 2018 by offering a Japanese cultural session before departure to teach students about basic etiquette and language used in Japan. In 2018 the students pointed out additional areas for improvement including clarity in assessment task and time management, "*the assessment task sheets did not provide enough/specific information in writing. The requirements were discussed verbally but they were not documented on the task sheets. Secondly time management was also highlighted as a challenge during the course, "better time management in Japan as sometimes we were late and missed doing things in Japan*".

6. Theoretical Mapping

This paper documents an initiative that began with the aim of finding alternative ways to embed the principles of the UNSDGs into engineering education. The hypothesis could be stated as: Exposing Australian engineering students to existing complex engineering solutions for sustainability challenges (in Japan) would "jolt" students into awareness of the need for system of systems approaches in engineering. The early sections of the paper describe the authors' rationale for pursuing this inquiry, the process followed and the results. In the implementation of this initiative, and subsequent reflection, several linked hypotheses – or assumptions – became apparent:

- The UNSDGs represent 'wicked' problems and their solutions are inherently complex.
- Disasters are chaotic and the limitations of known solutions are being increasingly identified.
- Engineering graduates may not be sufficiently trained in the identification and execution of complex problem solving at the level required for UNSDG implementation.

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- Education design (how the content is delivered) plays an equally important role as the content in engineering courses.
- There is scope to enhance the design of engineering courses to facilitate the development of complex problem-solving skills in graduates.

The themes of complexity and chaos and their relationship to best practice, order and expertise led the authors to a more in-depth review of the Cynefin framework, first published in a seminal knowledge management paper by Snowden (1999).

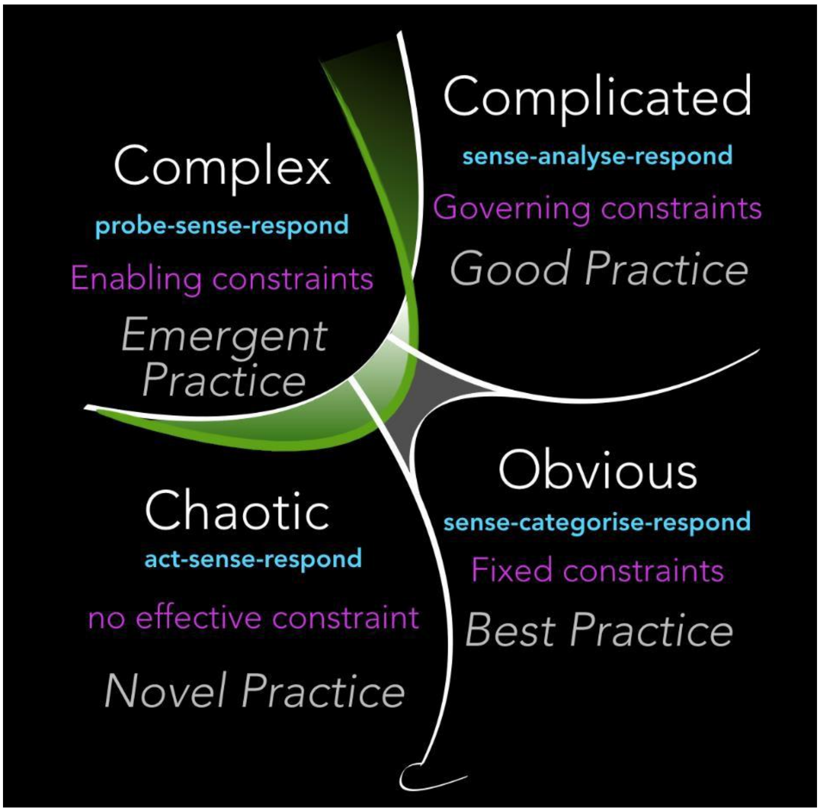

Figure 1. *Cynefin Framework (Source: Snowden, 2017)*

As shown in an updated liminal model of the Cynefin diagram, Snowden (2009; 2017) proposes that knowledge exists in four primary, related, domains: Obvious, Complicated, Complex, Chaotic. These are categorised according to availability of data and effectiveness of constraints in the organisation and application of the knowledge. Snowden argues that knowledge is either ordered or unordered, and when the relationship between cause and effect is known in the data, and constraints can be applied to influence this relationship, the degree to which this is true affects the rigour of systems thinking approaches that can be applied to successfully manage the context. "Very true" implies highly ordered, often practiced approaches, very untrue implies chaos, or highly unordered and no known approaches. Further, the role of "experts" or those who can advise on systems when one is not obvious, is limited to knowledge that is ordered and inherently known. Beyond this, the knowledge is yet to be ordered (unordered), and must be discovered using probes, or safe-to-fail experiments. Significantly, Snowden proposes that failure to correctly categorise the context in which one is working (or problem solving) is likely to result in dysfunction (or disorder).

6.1 Sense-Making Theory – dealing with Unorder

The first and second authors became aware of the Cynefin model early in this project, at the time the third author was working with this theory in a related engineering discipline. Having then viewed the project through the Cynefin lens (consciously and otherwise), the authors were expecting to find a direct correlation between Cynefin and their observations. Interestingly, this lens is what led to the later articulation of some previously "unconscious" hypotheses.

It is clear in Cynefin terms that the project itself was operating in the complex domain: the development of engineering courses specifically designed to teach students how to unpack and implement the SDGs within engineering solutions is emerging (Byrne et al., 2013). There is no existing best practice model, nor any specialist expert (solutions continue to require high levels of interdisciplinarity, which as the student feedback shows is not common practice or expectation for engineering graduates). The authors therefore began to probe more broadly into this challenge within the education literature, specifically seeking examples of action learning, behaviour change and complex problem solving. They first examined the course materials with a Cynefin lens, interested in understanding the proportion of course content that students were being exposed to unordered knowledge, either by experiencing knowledge in an unordered way, or by learning about the ways people in Japan had responded to situations that could be described as complex or chaotic. Table 5 presents a matrix of teaching intentions (shaded), documenting where students could identify the influence of one or more Cynefin quadrants in relation to the course modules. Several examples are provided below the table.

Lecture examples include:

- Smart agriculture: farmers in Japan collect data using remote sensor networks and satellites and share it on an open database, allowing them to make real time and informed decisions in the face of unprecedented weather conditions or natural disasters as well as optimise irrigation and fertilising systems. Technology is answering the questions, '*What day should I sow for an optimized yield', 'Where and when do I need water and fertilizer and how much', 'In the occurrence of this weather event when should I plant my crop and what is its probability of success*?'
- Disaster resilience: Subway stations are equipped with automatic flood gates to prevent water flooding the underground network and Shinkansen (high-speed trains) have an automatic stop feature which is activated after ground tremors are picked up by remote sensors and activate the automatic stopping of trains in the area. Supply services such as water, electricity and sewage are anchored to bedrock in disaster prone areas to reduce outages in the aftermath of a natural disaster. US$1 billion has been invested to equip residents and visitors with the knowledge to help themselves and others to survive an earthquake and resulting tsunami.

Table 5. *Coursework outline International Engineering Practice Source (Desha and Caldera, 2019)*

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Timing	Lecture/ Activity	Cynefin Quadrant of Consideration			
		Simple	Complicated	Complex	Chaotic
Week 1-3	Japanese Cultural and Language Immersion				
Week 3	*Assessment: Carbon Offset Report*				
Week 4-5	*In-Country Experience*				
- Day 1	Evening Networking Function (Chubu)				
- Day 2	**Toyota Manufacturing Plant Tour**				
- Day 3	Nagoya local tour				
- Day 4	Smart and resilient agriculture (Chubu)				
	Waste and Resource Recovery (Chubu)				
	English Cultural Session (Chubu)				
- Day 5	SCMAGLEV & Railway Park				
	Nagoya Port & Aquarium				
	Nagoya Castle				
- Day 6	Hamaoka Nuclear Facility				
- Day 7	Hiroshima Peace Museum				
	Miyajima Island Village and Gates				
- Day 8	Kyoto temples and built environment touring				
- Day 9	Introduction of Smart Grid System on Campus				
	Transportation in Japan (Chubu)				
	Health GIS in Japan (Chubu)				
	Super Conductors: The future of energy (Chubu)				
- Day 10	Coastal Cities Resilience				
- Day 11	Kyobashi Station and Circular Garden				
	Trade Investment Queensland				
	Tokyo Tower				
- Day 12	Miraikan Science Museum				
Week 7	*Assessment: Video Reflection*				
Week 11	*Assessment: Essay (Online submission)*				

Field trip examples include:

- Toyota Factory was highlighted as one of the richest learning experiences of the study tour. The company is a world leader in lean and green manufacturing or using a systematic and continuous approach to eliminate waste from the system and improve operational performance. Toyota isn't working to only

reduce physical waste but also wasted time, energy and resources, while also focusing on how its employees work. There is adjusted work environments and rolling work stations, focused on the comfort and improved productivity of the technician, situating everything in the right place to allow the employee to work more efficiently. Employees are also encouraged to contribute to the improvement of work stations and the flow of work, with daily meetings held on the factory floor, encouraging employees to raise concerns or suggestions to improve the process.

- The Hamaoka nuclear power plant showed an incomparable level of proactiveness with over seven countermeasures. This was influenced by a past traumatic event, the Fukushima accident, which enforced them to prepare for the worst circumstances.
- The 'Shinkansen' or bullet train is inspired by nature, where its aerodynamic shape is modelled on patterns observed in nature to reduce friction and sound losses. The modern Shinkansen also operates with an auto braking feature, which activates braking and demobilizes acceleration when two Shinkansen's are detected to be within a certain distance of each other, before the driver would be aware. Japan Rail's latest project is the MAGLEV, a Shinkansen which runs on superconducting magnetic levitation technology, which has been in development since 1962 and is planned to be in operation by 2027, featuring a top speed of 505km/h.
- This exercise confirmed the authors' emerging belief that the course design was contributing to the preference for ordered thinking in engineering design. To test the validity of this theory, the authors next reviewed the literature on learning theory and considered the thematic development of theoretical approaches to professional education. This exercise highlighted a subsequent challenge as discussed in the following section.

6.2 Learning and Teaching Theory ('How')

Knowing what to apply (what principles and insights), how to integrate the critical knowledge and skills arising from sense-making and behaviour change theories, and when within the engineering curriculum is central to educational practice. Caldera et al (2019) discuss this opportunity within a conference paper presented to the Australasian Association of Engineering Education (AAEE) conference (Brisbane, 2019), on "*Biggs + ACAD =*

?" Documenting an international pilot to address the 'Time Lag Dilemma' in education for sustainable development". Reflecting on the last two decades of key literature on engineering education and behavioural sciences it is evident that there is a wide range of perspectives across engineering disciplines regarding what sustainability is and what urgent need for engineers to be skills with relevant competencies (Desha, 2013; C. Desha, Hargroves, Dawes, & Hargreaves, 2013). The first author has previously written that resource management, digital technology, values, ethics, transdiscplinarity and systems-and-complex thinking are critical competencies for 21st century engineers if the UNSDGs are to be implemented (Byrne et al., 2013).

There are a number of researchers exploring the realm of behaviour change which can readily be considered within the context of professional practice – and in this case within the context of engineering practice. Behaviour change occurs as a result of many factors converging to support the development of knowledge and skills; shaping and strengthening habits in accordance with "how, when and where it was learned". These ideas of building on prior knowledge, embedding new knowledge into practice, authentic problem solving, impact of knowledge

sequencing, and metacognition are central to constructivist learning theory (Kolb, 1984; Krathwohl & Anderson, 2009; Merrill, 2002; Mezirow, 1981; Thorndike, 1927)

The challenge appears to be applying these theoretical foundations in the context of university education, where the time-lag dilemma for engineering education is well known (Desha, 2013). The first author has also written

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extensively on the challenges for designing curriculum to support the development of graduate skills relevant to solving climate change and sustainable development, looking at strategies including peer learning, fostering interdisciplinary networks, intensive experiences and study tours (complementary 'flagship' activities), information portals, and multidisciplinary projects.

6.3 Behaviour Change ('Why' and 'Who')

The experience of designing, delivering and evaluating this course has pushed the boundaries of rapid transformation curriculum renewal in terms of the expectations placed on both students and educators of sustainable engineering theory. A paper like this offers the opportunity to stand on the outside and critique the development of thought processes and responses in students, and also the degree to which the teaching embodies those very concepts – "do as I do". As highlighted in the introduction to this paper, the authors have focussed strongly on a range of ideas relevant to thinking differently about hard (wicked, complex) problems, including:

- Problem-solving strategy: Think Small (Gallagher, 2017)
- Prompting behaviour change: Nudge (Thaler & Sunstein, 2009)
- Dealing with risk: Black Box Thinking (Syed, 2015)
- Bigger Picture: Seeing what others don't (Klein, 2013)
- Knowing when to look up, and when to copy patterns: Thinking, Fast and Slow (Kahneman, 2011)
- Knowing when to lead autonomously and when to lead from the front: The Starfish and the Spider (Brafman & Beckstrom, 2006)

Very relevant to behaviour change is Kubler-Ross' stages of grief and dying which has been adopted by the management community as the "Change Curve". The first stages, denial and anger, can often be observed in the unlearning (Becker, 2007) process. Macdonald, Burke, and Stewart (2018) describe the shift from unconscious incompetence to conscious incompetence as dissonance "the point at which one recognises that their perception of reality and reality itself cannot be reconciled until they change behaviour". Gartner have also modelled Kubler- Ross' theory in their hype cycle, ascribing the values to technology waves and consumer acceptance (Hype Cycle Research Methodology, n.d.). This cycle of reaction to acceptance is visible in national approaches to climate change, peaks and troughs in popularity, periodic proliferation of related commercial activities, and the wholesale adoption of UNSDGs globally.

With reference to the World Engineers Convention paper by the same authors, on "*Foundations and Horizons: The Critical Role of International Coursework to Engage Students in Engineering for the 21st Century*" (Desha & Caldera et al., 2019), we find a useful point of reference for colleagues attempting to move beyond rhetoric and awareness, to develop engineering graduates who can deliver sustainable solutions towards the fulfilment of the UN SDGs.

A significant implication for urgent attention is that professional education psychologically anchors students in the domain of the expert – *Complicated* in Cynefin terms. When students experience contexts as the 'new and novel', without appreciating the Complex and Chaotic, there is potential for loss of identity and sense of belonging in the profession leading to shut-down on the further development of self (Maslow, 1943), and at the very least a dissonance trigger. If not well managed in the learning process, students (and later professionals) are apt to discard any knowledge further reinforcing this dissonance. Education programs that aim to prepare graduates for unexpected, unordered contexts – which the UNSDGs ask of engineers – must go sufficiently beyond declarative knowledge (Bloom, 1956), and recognition-primed decision making (Klein, 2013). This means going beyond exposing them to novel circumstances frequently such that that they might reproduce outcomes, to ensuring they are comfortable with uncertainty and lack of data. Further, *it requires reinforcing that such unorder is not a negative reflection on their professional capacity but a symptom of the ever-increasing complexity of our world, and the changing role of engineers and other professions in responding to it collectively*. The third author has previously written about the disruptive nature of this type of change in embedded education practice, arguing that it requires careful planning to ensure success (Hutchinson, 2013).

Students were particularly alert to the potential for conflict emerging from wicked problem solving. "*Without having the ability to resolve conflicts within any discipline, a simple situation could become a complicated one if it's not handled appropriately, as demonstrated in the Cynefin framework. Wide scale problem solving abilities within the transport sector require a multi-discipline approach across public, active and private model*" (S18-8).

The authors' conclusion is that development of complex decision-making capacity in undergraduate engineering students involves overlapping a number of theories as summarised in Table 6. This spans the theories of "how we learn" – sequencing and stages, learner maturity, structural rigour (Argyris, 1977; Becker, 2007; Bloom, 1956; Delahaye, 2004; Gagné, 1965; Kolb, 1984; Krathwohl & Anderson, 2009; Merrill, 2002; Snowden, 2000; Thorndike, 1927) "how we organise and apply what we have learnt" – knowledge (Kahneman, 2011; Klein, 2013; Snowden, 2000) and "how we manage our emotional/human responses to unexpected knowledge gaps and change" (Geels, 2011; Kotter, 2012; Macdonald et al., 2018; Maslow, 1943; Taleb, 2012).

Table 6: *A summary of developments in ontology and the impacts for teaching UNSDGs*

Developments (Key resaercher/s)	**Emergence**	**Ontology**	**Impacts for teaching UNSDGs**
Laws of Learning (Thorndike)	~1932 published in stage:	Behaviourist theory	Adult learners bring experiences and perspectives to learning. These greatl influence how they process and construct knowledge. Different types of knowledge manife: in different processing skills (eg reca discrimination, understanding concepts, applying rules, solving problems). Experiences and authentic (real life) problems provide efficient mechanisms for exposing adult learn to new concepts, developing deeper skills and metacognitive process and relating new knowledge to old. Denial and resistance are common reactions to new knowledge that acts conflict with old knowledge.
Hierarchy of Needs (Maslow)	1943	Psychological health	
Types of Knowledge (Bloom, Killen, Andersor and Krathwohl)	Developed as behaviorist theory by Bloom in 1950 extended by Anderson an Krathwohl to cognition (2001) then by Killen to divergent thinking (2005)	Behaviourist theory Cognitive theory - knowledge Learning theory – instructional design	
Nine Events of Instructio (Gagne)	Developed in a military setting in 1962 and extended in 1987	Learning theory - Instructional design Workforce development	
Adult Learning Theory – Andragogy (Knowles)	Andragogy was first coin in 1833 by Kapp a developed by seve authors before Knowl argued adults learn differently from childr in1968	Adult Education theory Adult psychology Workforce development Experiential learning theory	

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Stages of Grief (Kubler Ross)	1969, extended to change management, then Bridge published Managing Transitions in 1991. It is unclear who first brought Kubler Ross to change management.	Psychology theory – Grief and loss, Change management, Organisational Psychology, Leadership Cognitive theory - Reframing	Experiences that include metacogniti processes (eg reflective journals) provide opportunities for the learner t construct new meaning and mental models.
Double Loop Learning Theory (Argyris, Schon)	1974	Behavioural theory Cognitive theory – Experiential learning Organisational psychology	Relating UNSDGs and implementatio approaches to undergraduate students in first world environments helps to minimise some of the conflict arising from authenticy ("relevance of this to me").
Transformative learning (Mezirow)	1981	Cognitive theory – perspective	
Stages of Learning, Experiential Learning (Kolb, Delahaye et al)	First published by Kolb in 1984 and extended by Delahaye et al 1994	Cognitive theory – Experiential learning Andragogy/adult learning theory	In the 1980's education generally, an especially professional education, became more aligned with business needs to automate. Emergent theorist focussed on management systems to support these aims, and were less learner centric.
Recognition Primed Decision Making (Klein)	1993	Behavioural theory Cognitive theory – mental models Experient learning theory	
Eight Stages of Change (Kotter)	1996	Leadership theory – Change management Organisational psychology	This period delivered signifcant thinking on the interplay between systems engineering and managemen – how systems thinking, when applie to human captial, can reduce waste an improve performance, consistency an predictability.
Sensemaking, Cynefin (Snowden)	1999 with the liminal pha added in 2018	Systems theory – Complexity Cognitive theory – knowledge	
Five Principles of Instruction (for adult learners) (Merrill)	2001	Adult learning theory	
Unlearning (Becker)	2007	Cognitive theory - Experiential learning Behavioural theory – change Adult learning theory	Out of this came deeper understandin about problem solving contexts (Cynefin), automatic reponses to problems

Developments (Key resaercher/s)	**Emergence**	**Ontology**	**Impacts for teaching UNSDGs**
Systems Leadership (McDonald et al)	2006	Complexity theory - Systems thinking Behavioural theory Organisational psycholog	(based on experience) and working effectively with dissonance and resistance to learning. The relationship between system (processes and procedures) and behaivor were laso under the spotlight.
Antifragility, Black Swan (Taleb	2007 (Snowden and Taleb are currenlty engaged in Marx/Engels type conflict	Systems theory – Complexity Cognitive theory – distortion, error	Simultaneous catastrophes in the western world (GFC, 9/11 etc) saw the concept of failure and how to treat it both in a risk management sense and a learnin tool gain popularity in the early 2000's. The relationship between experience and systems were looked at closely. The emergent educational need was to prepare for the unknown and leverage small failures to devise solutions to wicked problems.
Memory and experience (Kahneman)	2011	Cognitive theory – experiential learning Systems theory – Complexity	
Multi-level perspectives (Geels)	2011	Innovation theory Behavioural theory – change, cognitive dissonance	
Black Box Thinking (Syed)	2013	Cognitive theory – distortion, error	This development highlights the need to change how we view the dynamics of professionalism, limitations of knoweldge and multidisciplinarity in the context of solving wicked problems. Students learning about UNSDG must practice this way of workin Learning needs to include unsolvable or very difficult problems, where the assessment focussed on the interpersonal skills and creative melding of divergent bodies of knowledge a well as the application of core course content.

The course employed a range of these strategies to create the conditions for behaviour evaluation in the students. Importantly, the authors note that reflection, review and metacognition are repeated themes in the literature in the context of bringing awareness to changed behaviour. The use of various reflective learning strategies during the course highlights this.

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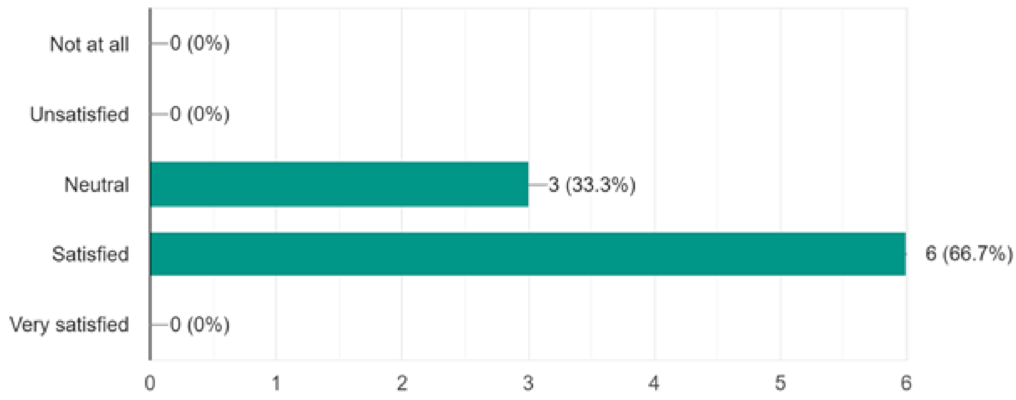

Figure 2. *An example of student satisfaction regarding the mind mapping exercise*

For example, to consolidate student perspectives, mind mapping exercises were adopted and feedback about their mind mapping experience was also gained through the survey. This tool demonstrated that the brain works by beginning with a central focal point and working outward in a random yet organized fashion. Mind mapping engages and focuses on using visuals along with the traditional verbiage from lectures and tests. Figure 2 shows that the majority of students were satisfied with the mind mapping exercise.

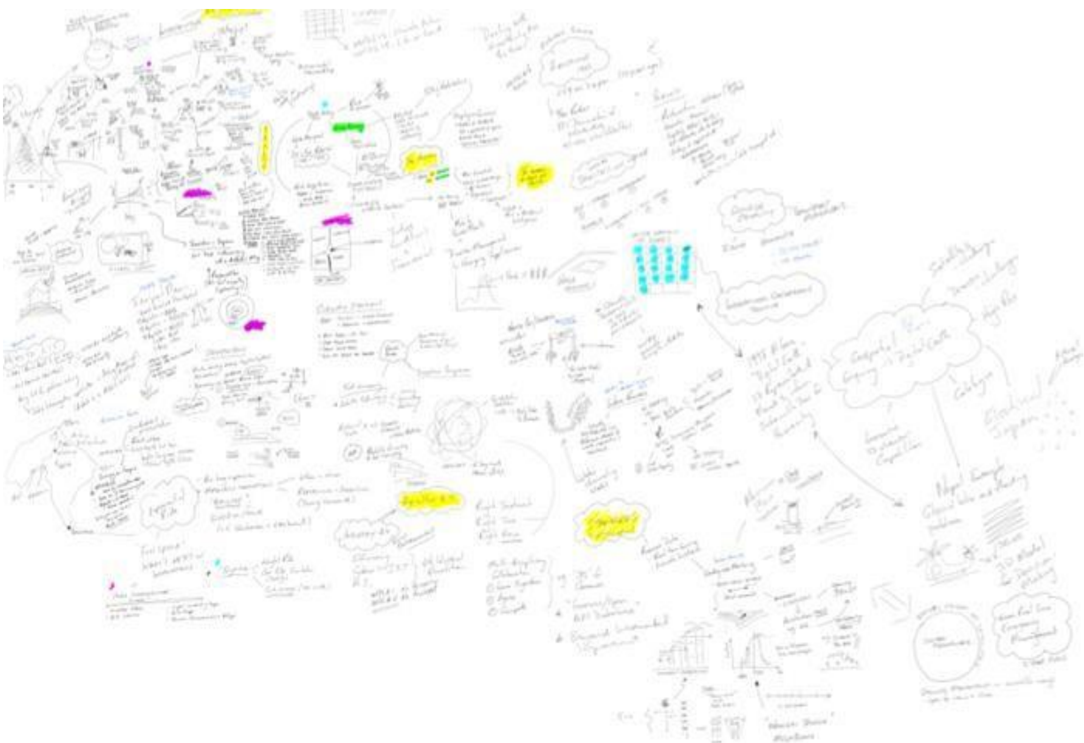

Figure 3. *An example of a consolidated mind map from the field trip*

Overall, students reported the value of these reflections toward their improved understanding of the need for multidisciplinary and novel approaches to embedding the UNSDGs in engineering practice. The students stated key benefits of mind mapping, such as "*everyone working together and hearing different opinion*," "*drawing out knowledge and memories of the trip*," "*effective way to facilitate group discussion about complex topics*," and as "*a helpful tool in comprehending the whole scope of Japan and this trip*". "*Processing the information shown from the growing innovation and infrastructure in Japan, I was able to establish a connection between the UNSDGs, EA competencies and the complex innovation and infrastructure in Japan*" (S18-8, S18-9).

7. Conclusions

This paper has documented an ethnographic study into the use of an international intensive course on International Engineering Practice, including the analysis of data from two experiences of implementation, in 2017 and 2018 (Nagoya, Japan). The paper has explored the value of the course with respect to shifting student appreciation of context and shifting perspective towards re-engineering social and technical systems structures for thriving in the 21st Century. Several aspects of the course have been discussed in relation to the key intentions for shifting behaviour, including learning about advanced technologies, innovative processes, promotion of sustainable practices and the strong resilience demonstrated by the Japanese culture.

The skill-sets required to deal with future unknown problems are well-known, including interdisciplinarity. The challenge is maintaining disciplinary expertise while enabling team-play with a specialisation. This involves thinking less of self as the only expert in a problem-solving context, and more about recognising the futility of some disciplinary knowledge in certain contexts (i.e. this won't work here) - and replacing it with other expertise, or 'starting from scratch'. Inspiring the ability of graduating students to say, "*I learned how to do something once - I can do this again when needed*". Students are shifting in their self-awareness of the context for engineering challenges, and their perspectives for improving practices and outcomes for society.

The authors have documented an historical evolution of thinking about decision-making, with Cynefin concluded to be a useful tool for sense-making in relation to documenting coursework learning (see Table 6). Considering the experience through the lens of the Cynefin framework, it is concluded that the course is making progress in enabling undergraduates to develop practical skills to take challenges faced in the engineering discipline and create opportunities for the future. For the authors, the question herein concerns enabling more of the student cohort to develop a factfulness mindset that enables better decision-making. It was evident that this experience has enabled to broaden their horizons on international engineering practice and shift their perspective in role of engineering, importance of interdisciplinary teams, and resilient infrastructure. However future scholarship will need consider how these learnings from an international experience can be translated into a local or virtual experience that is more accessible for more students.

The findings of this paper have implications for entities accrediting undergraduate programs in universities, providing rationale for embedding context and perspective in the degree - as a motivational benefit and as a potential opportunity for transforming practice towards embracing complexity, failure and viewpoints of other culture.

They provide a relevant and useful point of reference for colleagues attempting to move beyond rhetoric and awareness, to develop engineering graduates who can problem-solve towards delivering sustainable solutions.

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There are immediate implications for recruitment and retention strategies in developing tangible career-context and commitment to study from first year.

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Personal competencies for sustainable consumption

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Abstract
Individual consumption patterns still constitute a main contributor to the current environmental and socio-economic jeopardies of human society and hence represent a major challenge in the pursuit of sustainable development. Education for Sustainable Consumption (ESC) is considered one of the most powerful tools to influence individual consumer patterns. A competency-based approach toward ESC aims to (1) stimulate the acquisition of competencies that enable learners to consume in a way such that their behavioral impacts correspond to their sustainability-related intentions, and (2) initiate reflective processes on prevailing societal norms and to empower learners to relate their own values and purposes in life to these norms. As I argue in this paper, current conceptualizations of competencies for sustainable development and sustainable consumption tend to overemphasize intellectual and methodical competencies and neglect affective-motivational ones. Analyzing the evidence on challenges of sustainable consumption and related learning activities, I claim that personal competencies, especially affective-motivational ones, precede a meaningful confrontation with content related to SC and are essential for transformative ESC. These personal competencies include self-awareness; holding and being connected to intrinsic, sustainability-based values; emotional resilience and personal well-being, based on the ability to take care of oneself and mobilize personal resources, including self-efficacy, self-acceptance, mindfulness, and the capacity for pleasure; ethical qualities, such as empathy, openness, and gratitude, as well as positive attitudes toward the future. ESC that does not address these competencies does not only risk to undermine behavioral changes, but might also stabilize unsustainable behaviors by triggering negative emotions and subsequent psychological coping mechanisms. For this reason, I suggest to more strongly consider personal competencies as envisaged learning outcomes of ESC and direct related learning activities to the systematic stimulating of these competencies. Further research and practical experimentation is needed to develop pedagogical formats in which personal competencies can be systematically developed.

Keywords: Sustainable Consumption, Education for Sustainable Consumption. Competency-based approach, Personal Competencies

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1. Introduction

Individual consumption, understood as all actions of procurement, use and disposal of things and services that serve to satisfy needs in different areas of life (Fischer et al., 2011), constitute a main contributor to the current environmental and socio-economic jeopardies of human society and hence represent a major challenge in the pursuit of sustainable development (SD) (Alfredsson et al., 2018). Education is considered to carry a strong potential to change individual consumer patterns. Since the beginning of the 21st century, sustainable consumption (SC) has emerged as a cross-cutting theme and a key concern within the debate about Education for Sustainable Development (ESD). It can be defined as consumption that contributes to create or sustain external conditions that allow all human beings today and in the future to meet their objective needs (Fischer et al., 2011) and has been conceptualized as Education for Sustainable Consumption (ESC) as a sub-field of ESD (IMELS, 2007). ESC can be construed as a means to develop competencies for SC, so that it serves both behavioral and learning purposes (Fischer & Barth, 2014). On the one hand, ESC aims to stimulate the acquisition of competencies that enable learners to consume in a way such that their behavioral impacts correspond to their sustainability-related intentions; on the other hand, it intends to initiate reflective processes on prevailing societal norms and empowers learners to relate their own values and purposes in life to these norms. As such, ESC does not only address learners as consumers, but also as consumer citizens (Fien, 1997).

In light of the relevance of SC for sustainable development, there have been surprisingly little attempts to describe specific consumption-related competencies. Fischer & Barth (2014) provide a list of seven key competencies whose acquisition is supposed to enable individuals to engage in the cause of SC, both indirectly (as consumer citizens) and directly (as private consumers), namely:

1) Reflection: Competency to reflect individual needs and cultural orientations
2) Action: Competency to plan, implement, and evaluate consumption-related activities
3) Role-Taking: Competency to critically take on one’s role as an active stakeholder in the market
4) Communication: Competency to communicate sustainable consumption
5) Knowledges: Competency to use, edit and share different forms of knowledge
6) ICT: Competency to use information and communication technology (ICT) interactively
7) Vision: Competency to think visionary and to consider interrelatedness

There have been, however, several conceptualizations of competencies for SD in general (e.g. de Haan, 2010; Wiek et al., 2011; Lambrechts et al., 2013). Lozano et al. (2017) provide a comprehensive overview of these conceptualizations. The authors identify twelve, partly interwoven competencies within the literature considered by scholars as important for promoting SD. These comprise

- systems thinking, describing the ability to understand and (scientifically) analyze complex systems,
- interdisciplinary work, meaning the ability to work in interdisciplinary contexts by drawing on knowledge and methods from different disciplines
- anticipatory thinking, which includes the envisioning and evaluation of possible futures and the ability to deal with risks and changes
- justice, responsibility, and ethics, understood as the ethics and sustainability of personal and professional behavior and the ability to describe, negotiate and reconciliate principles, values, aims, and goals for sustainability
- critical thinking and analysis, conceived as the ability to challenge norms, practices, and opinions and

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reflect on one's own values, perceptions, and actions

- interpersonal relations and collaboration, comprising communicative skills, the ability to deal with conflicts, and the willingness to learn from other perspectives
- empathy and change of perspective
- communication (in intercultural contexts) and the appropriate use of media/information and communication technologies
- strategic action, mainly understood as the ability to design, analyze and implement sustainability activities and projects
- personal involvement, including participation in creating sustainability initiatives, the willingness and ability to learn autonomously, innovate and take action, as well as self-motivation
- assessment and evaluation, meaning the ability to develop assessment standards, as well as to evaluate with respect to conflicts of interest and goals, uncertain knowledge, and contradictions, and finally
- tolerance for ambiguity and uncertainty, describing the competency to cope with conflicts, competing goals and interests, contradictions, and setbacks.

These competencies describe desired, well-established educational outcomes within ESD, some of whom have also been explicitly addressed within ESC (e.g. Sahakian & Seyfang, 2018). Stimulating them follows the overall logic to enable learners to address challenges they will encounter in their personal lives and professional careers (Lambrechts et al., 2013). UNESCO's (2017) list of "cross-cutting key competencies" for SD corroborates this pedagogical orientation. They suggest systems thinking, anticipatory thinking, normative competency, strategic competency, collaboration, critical thinking, self-awareness, and integrated problem-solving (understood as the integration of the aforementioned competencies) as those competencies "necessary for all learners of all ages worldwide" (p. 10) and relevant for all SDGs, including SC. This list strongly overlaps with the previous competencies, yet adds the ability "to deal with one's feelings and desires" (ibid.) as part of self-awareness competency.

It is the aim of this article to find out whether the presented competencies adequately cover SC-related challenges. For this purpose, I will analyze existing evidence on challenges occurring when individuals (1) intend to change their consumer behavior and (2) engage in SC-related learning activities. These dimensions reflect both instrumental and emancipatory purposes of ESC that a competency-based approach purports to reconciliate (Fischer & Barth, 2014).

2. Challenges of sustainable consumption

As Schwartz and Howard (1981) and later Klöckner and Matthies (2004) have suggested in their model of normative decision making, consumer actions can be distinguished in four stages, namely (1) the attention stage, (2) the motivational stage, (3) the evaluation stage and finally (4) the behavioral stage. The attention stage covers the necessary preconditions to initiate SC, which are (a) the awareness of the need to consume sustainably, (b) the awareness of the relevance of one's individual behavior with regard to that need and (c) one's perceived behavioral control, that is to say an individual's perceived ease or difficulty of performing the particular behavior (Ajzen, 1991). Obviously, knowledge plays a crucial part at this stage both for forming the intention to change one's consumer behavior and for making sure that the actual impact of one's action corresponds to this intention. Without awareness of the impact of one's own consumption and knowledge about more sustainable alternatives,

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abandoning unsustainable consumer patterns is not possible. Impacts of individual consumption, however, are often not directly observable for consumers due to the lack of temporal, spatial and/or social closeness (Trope & Liberman, 2010, Ekardt, 2017), and, in certain cases, are explicitly concealed (Frank, 2017). In addition, assessing the actual impact of specific behaviors can be complex and related information ambivalent (e.g. Rosi et al., 2017). Presuming that a certain behavior can be identified as sustainable, individuals need practical knowledge in order to act accordingly. If one intends to reduce meat consumption, for example, one needs to know how to compose one's diet in order to avoid nutrient deficiencies, and how to prepare vegan or vegetarian dishes (e.g. Frank, 2017). In sum, at the attention stage, pursuing a sustainable consumption requires a fair amount of theoretical and practical knowledge.

Nevertheless, knowledge is not sufficient for consuming sustainably. Especially in Western societies, many people consider environmental protection important and express their willingness to restrict their individual consumer behavior for this purpose (BMUB, 2015). Yet despite their knowledge of the negative consequences of their consumer behavior, just few people act accordingly, showing that growing environmental knowledge and awareness does not necessarily lead to increased pro-environmental behavior (Grund & Brock, 2019). This suggests that other factors come into play when it comes to sustainable consumption.

One of these factors is the perceived behavioral control of an individual. Regardless of practical skills a person might possess, one can still hold beliefs that hinder her from taking actions (Ajzen, 2001). One might, for example, doubt one's ability to abandon meat. In fact, the importance of the belief in one's ability to succeed in a specific situation or task and to realize one's intentions for pro-environmental behavior – commonly referred to as self-efficacy, has been largely discussed in the literature: On the one hand, if individuals hold limiting beliefs about their abilities to reach their goals, this will keep them from engaging in sustainability-related action (e.g. Landry et al., 2018); on the other hand, a high self-efficacy encourages individuals to take action (e.g. Geiger et al., 2017). Connected to individuals' self-efficacy is their general emotional attitude toward sustainability-related problems: For one thing, feelings of despair and helplessness generally reduce individuals' willingness to engage with these problems (Stevenson & Peterson, 2016), entail fatalistic opinions, and can lead to fatalistic behavior, motivated by the idea that taking or not taking action has the same result (Thompson et al., 1990). For another thing, "constructive hope" (Ojala, 2012), that is hope that is not based on denial, has a positive influence on pro-environmental behavior (see also Grund & Brock, 2019).

At the motivational stage of the normative decision making model, further challenges for SC become visible. Schwartz and Howard (1981) distinguish three different types of motivations that are activated, namely (a) one's internal value system, (b) the motive of behaving in accordance with the expectations of relevant others (social norms) and (c) non-moral (e.g. economic) motives. Sustainability has turned into a strong normative vision over the last years (Herbrik & Kanter, 2016). In light of an increasing visibility of and discourse on sustainability-related problems, openly confessing one's consumptive 'sins' becomes less socially acceptable (Herbrik & Kanter, 2016; Ekardt, 2017), regardless of one's actual behavior. In social milieus in which sustainability plays a pivotal role, allegedly unsustainable consumer behaviors, such as eating meat, become morally reprehensible (Šedová & Slovák, 2016). The recently coined term "flying shame" (Spiegel Online, 2019) suggest that similar trends enter the social mainstream, turning the concept of sustainability into a social norm. While this trend might carry a positive potential (Ekardt, 2017), it can also lead to psychological reactance, describing a motivational arousal to offers, persons, rules, or regulations that threaten or eliminate specific behavioral freedoms (Brehm, 1966). Furthermore, Maiteny (2002) has argued that if “behavior changes in reaction to regulations, incentives and/or anxiety alone, it is more likely to be ‘skin deep’, temporary and prone to revert back to old habits” (Maiteny, 2002, p. 299).

For a behavior change to endure in the long term, in needs to be rooted it in one’s intrinsic values. This is, however, not trivial. Values are personal choices about what is important in life (e.g. Plumb et al., 2009). They are relatively stable dispositions, structuring and guiding specific beliefs, norms, and attitudes that in turn can affect behavior (Feather, 1995). However, people are not necessarily aware of their values (Berghoff et al., 2018). Furthermore, the possible temporal and spatial distance of the consequences of unsustainable behavior makes it more difficult for individuals to realize that their actions are not in line with their intrinsic values. In addition, normative values, such as striving for sustainability, can compete with other values, like hedonism, convenience, or material wealth (Steg et al., 2014).

Schwartz and Howard (1981) describe the evaluation stage as the one where the costs of possible actions are anticipated and weighted, taking into account the previously activated motivations. There is now a large body of research addressing ‘costs’ of more sustainable consumer behavior in various fields of consumption (e.g. Steg, 2003; Morgan & Birtwistle, 2009; Ruppel, 2015; Frank, 2017). Although specific obstacles of pursuing sustainable consumption differ among different domains and consumer goods, similar patterns can be identified on the basis of the aforementioned types of motivations.

Consumption as understood here occurs as a result of a perceived need. As such, consumer actions serve a particular interest of the individual. Changing consumption patterns might endanger the realization of this interest. For example, the purchase of local and organic food might require consumers to visit the local food market, which is located further away than the conventional super market. Additional temporal resources and physical effort is needed in this case. Similarly, using public transport or abstaining from airplane traveling may result in the need of more time and even higher financial expenses. Emotions play a particularly important role when evaluating consumer activities (Hamann et al., 2016). If, for one, a consumer activity is accompanied by positive emotions such as pleasure or joy, anticipating this emotion can be a relevant driver for this activity. Eating meat or exotic fruits, spending one’s holidays in luxury resorts, or taking a hot bath are examples for such activities. Abandoning such behaviors possibly deprive consumers from such positive sensations. If, for another, a consumer activity is connected to negative emotions (fear, for instance) this might prevent individuals from engaging in that activity (Gifford, 2011). A vegetarian diet might, for instance, be associated with nutritional deficiencies and can therefore prompt health-related worries. Using public transport might be avoided due to fear of harassment. More generally, dealing with climate change might even be a reminder of one’s mortality, thereby evoking existential fear of death (Vess & Arndt, 2008).

Changes of individual consumption can become particularly challenging when they entail negative social consequences. This occurs when the prevalent social norm or the interests of others are opposed to sustainability-

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oriented values, for example refusing to eat meat or to use airplanes (Ruppel, 2015; Frank, 2017). In these situations, an individual's need to belong is threatened, in social psychology considered a "fundamental human motivation" (Baumeister & Leary, 1995).

Again, this threat can appear in two ways: either might consumer activities take place in social surroundings that are associated with particular positive feelings (e.g. sharing the family Christmas dinner) and one might feel deprived of this positive feeling in case of consuming differently; or one might experience or at least fear negative social reactions, such as disappointment, being asked for justifications, or even rejection (Frank & Stanszus, 2019). In addition, changes in consumption patterns can menace one's social identity, that is the portion of an individual's self-concept derived from perceived membership in a relevant social group (Tajfel & Turner, 1986). For instance, Ruby and Heine (2011) have shown how social images of masculinity and men's intention to adhere to these images make them prone to meat consumption and turn plant-based foods into less attractive options.

At the same time, conflicts of identity related to one's consumer behavior do not need to originate from opposing social norms. Instead, they can arise from the observation that one's actions do not correspond with one's sustainability-oriented values. This is because bringing the detrimental consequences of one's behavior into full consciousness can prompt feelings of guilt (Wang & Wu, 2016) and reduced self-esteem (Frank & Stanszus, 2019). More generally, being confronted with the pressing problems of contemporary society and feeling a sense of individual responsibility for these problems can trigger emotions of overwhelm, helplessness, and other stressful experiences (see also Brundiers & Wiek, 2017).

Such emotional burdens co-determine the action the person carries out at the behavioral stage. If an individual cannot deal with the emotional burdens described above, it is likely that one will engage in psychological coping mechanisms aiming to dissolve the unpleasant emotional state by repressing, neutralizing, or rationalizing the impact of one's actions. In addition, these coping mechanisms can entail a process of desensitization, meaning that students experience a feeling of indifference with respect to their consumption (Frank, 2017). People are not necessarily aware of these processes and the role they play regarding their consumer choices, as they often occur at an unconscious level (Hamann et al., 2016). To enable individuals to pursue problem-oriented coping strategies, it is necessary to help them become aware, and to find a way to constructively deal with the source of their emotional discomfort.

Klöckner and Matthies (2004) have suggested to integrate habitual behavior in the normative decision-making model. They argue that many consumer activities do not originate in choices based on a thorough reflection and evaluation of one's actual needs and values, but rather demonstrate a habitualized behavior. While the degree of reflection depends on the domain of consumption (Zundel & Kaufmann-Hayoz, 2011), ample evidence has been provided that certain forms of consumption, for example eating, can be considered strongly habitual and automatic (van't Riet et al., 2011). It is often a reaction to impulses or an emotional coping strategy for avoiding or suppressing negative thoughts and emotions, instead of being primarily based on physical needs or values. Thus, despite general willingness among consumers to eat in a healthy and more sustainable manner, strong habits and automaticity, impulsivity related to external triggers, and using food as a coping mechanism often restrict the control that people have over their food purchases and consumption. In order to change these habits, it is crucial to develop an awareness of the latter, including the external triggers that activate them and the potential coping function they fulfill.

So far, challenges of SC have been primarily described as arising from the discrepancy between sustainability-oriented values and actual behavior. The phenomenon of habitual consumption, however, points to a more fundamental challenge of SC that underlies the entire process of normative decision-making. Consumption is defined as an act that serves to satisfy one's needs. Consumer goods hence constitute potential satisfiers for individual needs and their use is supposed to make a contribution to achieving a good life (Fischer, 2012). Yet habitual consumer patterns make clear that individual consumption is not necessarily primarily rooted in one's actual needs. Max-Neef's (1992) classification of satisfiers provides an explanation for this disparity: He distinguishes between singular, synergistic, pseudo-, and inhibiting satisfiers. While singular and synergistic satisfiers address one or multiple needs at once, pseudo-satisfiers only simulate and inhibiting satisfiers even obstruct the satisfaction of one's own needs.

These reflections entail two consequences: Firstly, the selection of a (consumptive) satisfier might not be appropriate to satisfy individual needs and can hence fail in its original function to contribute to personal sustainability; secondly, much of the detrimental consequences of individual consumer behavior might be a result of inappropriate selections of (consumptive) satisfiers. In order for a consumer act to be sustainable it must address one's personal needs while external conditions are preserved that allow other human beings today and in the future to meet their objective needs. An awareness both for one's needs and the adequacy of satisfiers to meet the latter is a prerequisite for engaging in such actions.

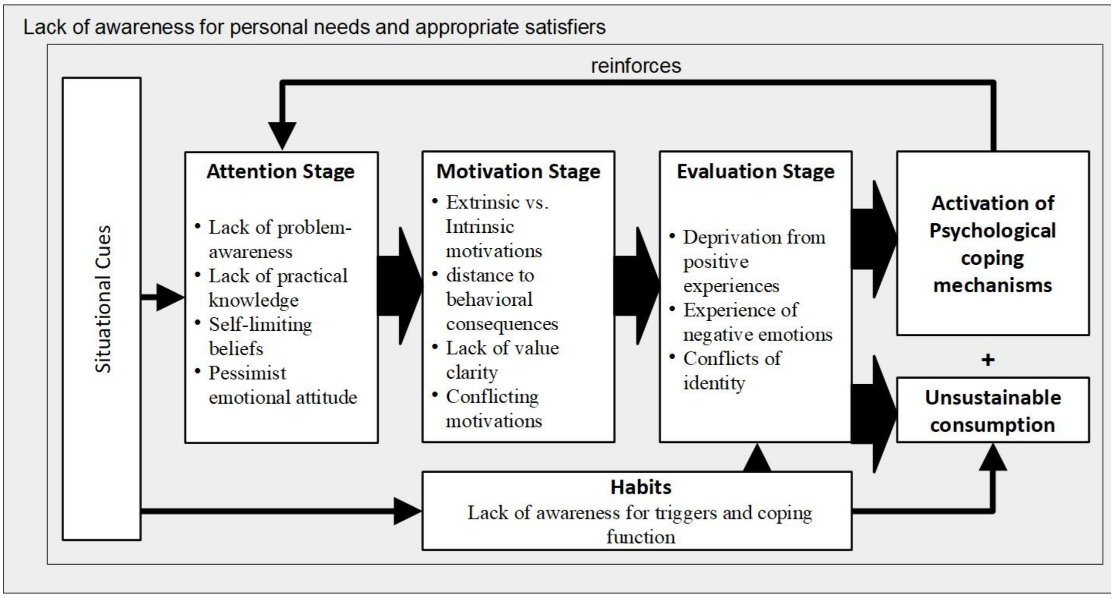

Figure 1*: Challenges of SC based on Klöckner & Matthies (2004) normative decision-making model*

Figure 1 summarizes the described challenges of SC at each stage of the decision-making process. It must be kept in mind that SC is usually not a matter of a single consumption act, but a repeatedly occurring process. As a consequence, the described challenges constitute potentially recurring obstacles both for the initiation and maintenance of SC patterns and require perpetual efforts to be faced and overcome (Frank, 2017).

Obviously, knowledge about the impacts of one's consumer behavior and possible alternatives remains a

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prerequisite for SC. This is where SC-related learning comes into play.

3. Obstacles for SC-related learning

As is the case for any learning activity, SC-related learning requires a confrontation with specific content. The manner of confrontation might vary from one area of consumption to another: Where sustainable alternatives to prevailing consumption standards are already identified, learners need to assimilate the provided information and translate them into action in order to pursue sustainable consumption patterns; in case of uncertainty, learners are supposed to take note of and evaluate ambiguous information, so that they can fulfill their role in (co-)developing and experimenting with solutions for unsustainable consumption, engage in public deliberation processes, and act as political change agents. Either way, the acquisition of SC-related content knowledge is an indispensable part of ESC, regardless of the didactic or pedagogical format in which this content is embedded.

A variety of learning theories have been dedicated to the question as to how individuals process new information and generate knowledge (Seel, 2000). Especially cognitive-constructionist perspectives have emphasized that individuals do not just receive information, but actively construct knowledge based on a subjective perception and interpretation of experience. This knowledge construction process is influenced by a series of content-independent factors, potentially impeding the alignment of actual learning outcomes with the content addressed within learning activities. Many general influencing factors (e.g. curiosity, perceived self-determination) are well-known in the scholarly debate and have been widely considered in educational practice (Ecclestone & Hayes, 2008). Some factors, however, do have a special relevance for ESD/ESC contexts, and they pose serious challenges for dealing with SC-related content. It is the identification of (some of) these factors that stands in the spotlight of this section. First and foremost, learning-related challenges can be a direct result of the difficulties described in the previous section. As I have illustrated, being confronted with the pressing problems of contemporary society, and feeling a sense of individual responsibility for these problems can be overwhelming or at least emotionally stressful. This state has been described as cognitive dissonance (Festinger, 1957). If one cannot support or dissolve this dissonance through behavioral change, it is likely that one will engage in psychological coping mechanisms aiming to dissolve the unpleasant emotional state, such as repressing, neutralizing, or rationalizing (the impact of) one's actions and thereby altering one's attitudes and beliefs. Especially the latter strategy negatively impacts further confrontations with related contents.

Rationalization is a process of finding post-hoc justifications for one's behavior, for example as a result of criticism or when one's behavior is perceived as discrepant with an integral aspect of one's character (Mercier, 2011). Rationalization processes help to soothe negative emotions when a person is unable to change or motivated to continue in a practice or belief that they may otherwise feel guilty about on account of dissenting perspectives (Gregory-Smith et al., 2013). It also plays an important role in maintaining a positive image of oneself (Jordan & Monin, 2008). Rationalizations are hence reasoning processes driven by the motivation to reduce or avoid the experienced emotional discomfort. One consequence of this motivated reasoning process is that people will often seek out arguments that support their own viewpoint (confirmation bias, Nickerson, 1998) while overlooking or dismissing arguments that challenge it (Ditto & Lopez, 1992). Their affective-motivational state precedes the examination of new information and hence determines their interpretation. As mentioned before, such processes usually take place on an unconscious level.

Confronting learners with established SC-related content hence entails two possible challenges: For one, it can prompt psychological coping mechanisms leading to the post-hoc justification and thereby stabilization of unsustainable consumer patterns; for another, it risks to activate cognitive biases, defined as the phenomenon that "individuals draw inferences or adopt beliefs where the evidence for doing so in a logically sound manner is either insufficient or absent" (Haselton et al. 2005, p. 725). Scholars have repeatedly suggested "possible ways to (re-)activate rational thinking and avoid affect heuristics in questions that require careful and rational efforts rather than fast and myopic answers" (Engler et al., 2019, p. 611). Part of these ways is to increase discursive-intellectual efforts and thoroughly evaluate and compare the various perspectives available regarding a specific content. This is usually what happens in case of ambiguous and uncertain SC-related topics.

There is, however, good reason to assume that ambiguous and uncertain SC topics can equally be approached by motivated reasoning instead of being guided by an epistemic evaluation of the provided arguments. Humans seem to show an emotional preference for certainties regardless of their~~its~~ epistemic justification (Okabe, 1912; Lund, 1925), which can also be observed in regard to SC-related topics (Frank et al., 2019). In order to deal with complex and uncertain knowledge, it is important that individuals show a motivation "to engage in and enjoy effortful cognitive endeavors" (Cacioppo, 1996 p. 197). Conversely, the confrontation with arguments cannot simply be understood as an epistemic examination of the facts provided. Instead, whether or not one faces existing evidence depends on one's willingness to undertake such examination. This willingness is directly dependent on the subjective theories (Groeben et al., 1988) people hold about what knowledge is, meaning that epistemic assumptions determine the way new information is processed (Hofer & Pintrich, 2002). For example, Muis et al. (2015) found that students who believed that the justification of knowledge about climate change was complex and uncertain experienced higher levels of enjoyment and curiosity, and lower levels of confusion, anxiety, and boredom than those expecting more unambiguous information. Building epistemic beliefs allowing to engage in and enjoy effort cognitive endeavors, in turn, requires the emotional resilience to cope with complexity and uncertainty.

The scholarly literature provides a series of strategies individuals can apply to circumvent the latter task. Kelley's (1971) discounting principle is one of them, according to which the confidence in a given statement develops proportionally with the number of alternatives available, regardless of their epistemic quality. Kruglanski and Webster (1996) introduced the concept of need-for-closure. The term 'closure' is used in the sense of arriving at a settled belief. Achieving closure or judgmental commitment on a question puts an end to the experience of ambiguity and delivers a feeling of having a firm answer. As argued before, individuals can have a practical interest to achieve closure in certain situations, for example when they are motivated to continue with a specific consumer behavior.

Sometimes consumer activities are also directly linked to constructs of identity (e.g. Frank, 2017), and we have a strong interest in maintaining a positive and consistent image of ourselves (Jordan & Monin, 2008). This interest will lead to a different intensity of confidence toward the provided evidence on the question at stake, a phenomenon the Kruglansky and Webster call the unfounded confidence paradox. Similar to this paradox is the already mentioned confirmation bias - describing the phenomenon that agents have a tendency to search for,

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interpret, favor, and recall evidence that supports the beliefs they hold rather than impartially dealing with new information (Nickerson, 1998) – or the myside bias, which is when people overestimate the amount of evidence that favors their position (e.g. Stanovich, West, & Toplak, 2012).

Opposing evidence, in contrast, can activate defense motivations (Masterson & Crawford, 1982), which in turn reduce individuals' receptivity toward such evidence and further stabilize their positions. Such reactions are by no means exclusive to allegedly unsustainable consumer patterns: Veganism, for instance, carries a great potential to convey identity, and people pursuing a vegetarian or vegan diet seem no less likely to engage in biased perception of counter-evidence to their own standpoint than meat eaters do (Frank & Fischer, 2018).

The social intuitionist model of moral judgement (Haidt, 2001) provides good theoretical ground to argue that this proclivity is not simply a result of insufficient rational endeavor. The belief that humans are rational agents has for long been the fundamental principle regarding theories about higher cognition (Haidt, 2001). Social intuitionism is an alternative to rationalist models of moral judgement. It is built on the premise that the affective system was undervalued by previous research. It integrates the dimensions of reasoning, emotion, intuition, and social context. According to social intuitionism, moral emotions and intuitions (usually unconsciously) drive moral reasoning and directly cause moral judgements, as opposed to rationalist models, where reasoning is understood as the conscious, step-by-step process of judgement (ibid.). Moral positions and judgements are hence primarily intuitive ("intuitions come first"). In an effortful process of searching for supporting arguments and causal explanations, these positions and judgments are then rationalized, justified, or otherwise explained after the fact. Haidt further claims that moral reasoning needs to be viewed as an interpersonal process that reflects social motives, for example belonging or recognition: "moral reasoning is usually an ex post facto process used to influence the intuitions (and hence judgments) of other people" (ibid., p. 814). He suggests that when people explain their moral positions, they often miss, if not hide, the core premises and processes that actually led to those conclusions. While the social intuitionist model does not rule out the possibility that discussing moral judgments and positions can lead to changes of the latter, it equally emphasizes the risk of cementing one's own and dismissing others' perspective. This process has been called attitude polarization (Lord et al., 1979) and observed when students discuss opposing evidence, for example, concerning meat consumption (Frank & Fischer, 2018).

In sum, dealing with SC-related content can entail a series of challenges. These challenges are mainly the result of motivated reasoning processes: Firstly, being confronted with the (unsustainable) impacts of our consumer choices can trigger negative emotional responses. Avoiding or resolving the emotional discomfort might require individuals to engage in avoidance strategies, psychological reactance, neutralization of rationalization processes. Secondly, dealing with complex and interdependent problems impede our psychological need for control and orientation. Thirdly, maintaining one's identity and the pursuit of social motives can influence the confrontation with SC-related content and lead to a biased perception of the latter. Importantly, intending to address these biases with more content is not conducive and rather risks to fuel the latter.

4. Personal competencies for sustainable consumption

The challenges described in the previous sections are primarily personal, that is to say they concern the inner states and processes of the individual. An ESC aiming to enable learners to consume in a way such that their behavioral impacts correspond to their sustainability-related intentions needs to build competencies that respond to these challenges. Such competencies include an awareness for habits, inner states and processes (emotions, motivations, values, needs and their satisfaction), and psychological coping mechanisms that are usually unintentionally activated. Individuals need an open and empathic posture toward their consumer patterns in order to overcome the (emotional) distance to the behavioral consequences. Furthermore, they need an emotional resilience to endure resulting unpleasant emotional states and the perseverance to pursue intrinsic values in light of reoccurring obstacles. A feeling of self-efficacy and a positive attitude toward the future as facets of "mindsets for sustainability" (Wamsler & Brink, 2018) are supportive in this regard. In addition, Hunecke (2018) has suggested that the cultivation of psychological resources help individuals to deal with the emotional challenges related to sustainability-related topics. These resources comprise the capacity for pleasure, self-acceptance, mindfulness, the ability to construct meaning with regard to one's life, and solidarity. Brundiers and Wiek (2017) point to a similar direction, underlining the importance of developing qualities such as compassion, empathy, gratitude, and mindfulness as well as the ability to take care of one's personal well-being in the face of mental and emotional distress. All these competencies can be called personal competencies for sustainable consumption – understood as abilities, proficiencies, or skills related to inner states and processes that can be considered necessary or sufficient to engage with SC (Frank & Stanszus, 2019)(Table 1).

Table 1: Personal competencies for SC

Competency	Description
self-awareness	awareness for habits, subjective theories, inner states and processes (emotions, motivations, values, needs and their satisfaction), and psychological coping mechanisms that are usually unintentionally activated
ethics	holding and being connected to intrinsic, sustainability-based values
emotional resilience	Ability to endure unpleasant emotional states Perseverance to pursue intrinsic values in light of reoccurring obstacles Reconciling
Self-care and access to personal resources (e.g. self-acceptance, self-efficacy, mindfulness, ...)	Ability to maintain a sufficient quality of one's inner situation and one's sense of well-being, including bodily experiences, thoughts, values, needs and wishes, or emotions
Ethical qualities	E.g. empathy, openness, gratitude
mindsets for sustainability	The established set of attitudes (toward oneself, the future, …) are such that they facilitate a constructive, pro-active posture toward the world

Comparing these competencies to the lists provided above reveals intersections, but also differences in terms of the competencies' main focus. Prevailing conceptualizations of competencies mention an awareness for inner states and processes, including habits and practices of need satisfaction. They also emphasize the importance of intrinsic motivations concerning SC and indicate a series of abilities an individual must possess in terms of dealing with and exchanging new information (e.g. ability and willingness for empathic communication). Finally, they

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highlight the ability to deal with feelings and desires in general and a tolerance for ambiguity and uncertainty in particular. Scholars have also made explicit that ESD/ESC would strongly benefit from learning settings that included not only cognitive, but also affective and psychomotoric dimensions (Wiek et al., 2011).

Nevertheless, they do express a strong focus on intellectual processes and the application of scientific knowledge and methods in order to reflect, analyze, evaluate, assess, negotiate, or plan in regard to sustainability-related topics. Personal processes, especially affective-motivational ones, play a minor role in these lists and remain largely unspecific. Having its main focus on intellectual and scientific-methodical competence, current ESD/ESC approaches epitomize the general tendency of ESD to prioritize cognitive skills and information transmission, particularly in upper schools and higher education (Shephard, 2008; Brundiers & Wiek, 2017; UNESCO, 2019). This tendency has been criticized by several ESD scholars, not least because of their tendency to neglect of individuals' "interiority" (Wamsler & Brink, 2018).

In contrast, this article provides evidence that the systematic development of personal competencies is of pivotal importance for ESC and precedes intellectual endeavor. That is not to say that discursive-intellectual inquiry into SC is irrelevant, but that it needs to be rooted in the development of personal competencies to be fruitful.

5. Conclusion

In the previous sections, I have argued that personal competencies, understood as abilities, proficiencies, or skills related to inner states and processes that can be considered necessary or sufficient to engage with SC, are of pivotal importance when aiming to enable individuals do engage with the topic of SC. This is because both consuming sustainably and learning for SC poses a series of challenges whose nature is primarily affective-motivational. While prevailing conceptualizations of SC-related competencies partly recognize personal competencies, they express a strong focus on intellectual and scientific-methodical competence. Affective-motivational processes play a minor role in these lists and remain largely unspecific. Not addressing these processes does not only risk to undermine behavioral changes, but might also stabilize unsustainable behaviors by triggering negative emotions and psychological mechanisms to cope with them. In line with other scholars, I therefore suggest to more strongly consider personal competencies as envisaged learning outcomes of ESC and direct related learning activities to the systematic stimulation of these competencies.

Such a reorientation of ESC poses new challenges to practitioners and researchers alike. Since personal competencies have not yet been subject to large debates in the field, there is little experience on how to stimulate them. More precisely, it remains an open question as to which learning activities and pedagogical approaches are most appropriate for this purpose. Singular attempts in this direction have been made (e.g. Murray, 2011; Brundiers & Wiek, 2017; Stanszus et al., 2017; Frank & Stanszus, 2019; Wamsler, 2019) and provide promising evidence regarding the possibility of developing personal competencies. However, such attempts still remain fragmented and the resulting evidence is often based on single case studies. Therefore, more differentiated and methodologically elaborated inquiry is required in this regard.

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The 12 Key Issues of Education for Sustainable Development

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Abstract

Education *for* Sustainable Development is about enabling people to constructively and creatively address present and future global and local challenges, and create more sustainable and resilient societies. Empowering learners to maintain responsible lives and to address complex global challenges calls for new approaches to learning which will support the development of vibrant green economies and societies, and the emergence of a "global citizenship". UNESCO is supporting countries to build education capacities, generate and scale-up actions, focusing on key issues as entry points for promoting sustainable development practices through education. The paper tries to elaborate and present 12 key issues for Education for Sustainable Development. They have been summarized after studying the available literature, enhanced by the author's own experience. Also, they were tested at an international meeting of educators for sustainable development. The key learnings have been found to be: holistic education, stakeholders' awareness, participation and cooperation, and building capacity of stakeholders. The challenge is timely evolution of the human society towards the deep transformation.

Keywords: Education, Sustainable Development, Key Issues, Deep Transformation, Principles

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1. Introduction

Sustainable Development (SD) was released by the United Nations (UN) World Commission on Environment and Development (WCED) report *Our Common Future*, most often called Brundtland Report according to its chairperson Gro Harlem Brundtland, former prime minister of Norway. It was officially introduced at the UN General Assembly in 1987. SD was defined as the development that »meets the needs of the present without compromising the ability of future generations". Today, it is described as the organizing principle of human development that fulfils long term needs of humanity and at the same time sustains the "ability of natural systems to provide natural resources and ecosystem services upon which society and economy depends". UN Conference on Environment & Development in Rio de Janeiro (UNCED, 1992) called for global partnership in SD. In chapter 36 of the Agenda 21 they proclaimed that "education has to be reoriented towards SD". This chapter identified four major thrusts to begin the work of Education *for* Sustainable Development (ESD): 1) improve basic education, 2) reorient existing education to address SD, 3) develop public understanding, awareness, and 4) training.

ESD followed the UN International Environmental Education Program (1975−1995) which had presented a vision and mobilized education for environmental awareness. ESD "allows every human being to acquire the knowledge, skills, attitudes and values necessary to shape a sustainable future" (UNESCO, 2018). It is "including key SD issues into teaching and learning – e.g. climate change, disaster risk reduction, biodiversity, poverty reduction, and sustainable consumption". In 2002 UN General Assembly decided to initiate the 2005−2014 Decade for ESD led by UNESCO (2014). It focused its efforts to four main areas:

1. Looking at education as a critical implementation tool for SD;
2. Reorienting education systems towards commitments of Millennium Development Goals (MDGs) and Education for All (EFA);
3. Networking and interaction among stakeholders in ESD;
4. Developing approaches for the assessment of progress in ESD.

The Global Action Program (GAP) on ESD is the follow-up program to the Decade of ESD. The GAP aims to contribute substantially to the 2030 agenda through two objectives:

- "Reorienting education and learning so that everyone has the opportunity to acquire the knowledge, skills, values and attitudes that empower him/her to contribute to a sustainable future.
- Strengthening education and learning in all agendas, programs and activities that promote sustainable development."

The GAP focuses on five priority action areas: 1) advancing policy; 2) transforming learning and training environments; 3) building capacities of educators and trainers; 4) empowering and mobilizing youth; and 5) accelerating sustainable solutions at local level. UNESCO (2018) published a review on issues and trends in ESD, aimed at providing policymakers, educators and other stakeholders with state-of-the-art analyses of the topic. ESD is placed at the center of the 2030 Sustainable Development Agenda and has been widely recognized as a key enabler of sustainable development and an integral element of quality education. The report contains 10 chapters about understanding and implementing ESD. Learning objectives for several Sustainable Development Goals (SDGs) are presented.

ESD is recognized as a key element of quality education and a crucial enabler for SD. The 2030 Agenda for

Sustainable Development clearly reflects this vision of the importance of appropriate educational response (UN, 2015). Quality education is explicitly formulated as a stand-alone Sustainable Development Goal (SDG No 4), and Target 4.7 on education specifically addresses ESD and related approaches (UNESCO, 2017). Education for SDGs is cited in this edition – for each SDG there are three groups of learning objectives: cognitive, socio- emotional, and behavioral ones. ESD is used to implement learning for SDGs, and some case studies are presented. Many education-related targets and indicators are being developed within the SDGs, too. 10 out of the 169 SDG targets are attached to Quality Education. They have been analyzed together with the above mentioned agendas of global organizations and the questionnaire results. Education, training and learning is

linked with all the other SDGs as was shown by the International Council of Scientific Unions and the International Social Science Council Review (ICSU & ISSC, 2015) – now International Council for Science, ICS. Education system is providing professionals, researchers and teachers for all the of human activity areas.

Education is believed to be closely linked to demography and resource consumption. While the first one reduces population growth rate, the second one increases consumption (McKeown, 2006). The most developed countries with the highest education levels have the highest per capita consumption rates. Therefore, ESD has to be reoriented towards decreasing consumption, requiring de-growth and life style revolution in developed countries. Reisch et al (2016) are suggesting 5 focus areas on research for sustainable consumption: 1) sustainable macroeconomics; 2) sustainable consumption, well-being and the "Good Life"; 3) sustainability in global supply chains; 4) alternative systems of provisioning for sustainable consumption; and 5) policies fostering sustainable consumption.

GlobeScan/SustainAbility Survey (GSS, 2019) evaluated the progress made on SDGs, and ranked their relative urgency. The 4th Goal – Quality Education ranked 3rd in progress made and 10th in urgency. Regarding attention within organization, it is now on the 5th place but in Africa and Middle East it is still the SDG receiving most attention. In the 2017 Survey, Quality Education was found to be the 2nd most important SDG for society to focus on, only Climate Change was higher as the impact importance. In organizational units the most attention was payed to Climate Action, and Responsible Consumption and Production while Quality Education was 5th.

2. The 12 key issues of Education for Sustainable Development

Higher education institutions (HEIs) have accepted and signed many declarations, charters and partnerships to improve the effectiveness of ESD. Lozano and al. (2013) have analyzed 11 declarations for sustainability in higher education and found that the elements:

- *Curricula, collaboration and outreach, operations, and research* were considered by almost all initiatives
- *Trans-disciplinarity, collaboration of universities,* and *'educate the educators'* were considered by about half of the declarations
- *On-campus experience, assessment and reporting,* and *the institutional framework* are cited by a small number of the initiatives, only.

In this paper, content of an ESD course was searched for by examining the available literature and using personal experiences. The first draft of the ESD 12 key issues was prepared for the Copernicus Alliance Conference (CA, 2019). During the Interactive Session, the discussion group supplemented the draft version, and added 3 key learnings and one challenge found by the discussion. The key learnings were: holistic education, stakeholders' awareness, participation and cooperation, and building capacity of stakeholders. The challenge was timely

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evolution of the human society towards a deep transformation – the strong sustainability. The improved paper has been further elaborated using literature sources and practical experiences. The key issues are organized in 4 groups (approach, contents, teaching, and organization) with 3 items each. They are intended to be used for teaching and learning about ESD at all grades but they have to be shaped to the level used.

The proposed **12 key issues of ESD** are:

1. **ESD scope**: SD and ESD definitions, education at all the levels (primary–tertiary), life-long, formal, non-formal and informal education, teaching & learning, ESD key milestones, ESD competencies, quality education, and weak and strong sustainability
2. **ESD policy**: vision, mission, peace, justice, and non-violence, democracy, rule of law, strong institutions, public awareness and participation, power and influence distribution, sustainable communities, cities, countries, and regions, and population control (towards zero-growth)
3. **ESD cooperation**: empowering and mobilizing youth and aged people, intergenerational cooperation, cooperation between stakeholders (institutions, companies, communities, etc.), and partnerships
4. **Environmental** pillar: climate change, adaptation and mitigation, pollution prevention and zero waste, life cycle approaches, biodiversity, disaster risk reduction, and the six Lisbon principles (responsibility, scale-matching, precaution, adaptive management, full cost allocation, and participation)
5. **Social** pillar: human rights, hunger and poverty eradication, security, clean water and sanitation, health and well-being, reduced non-equalities (gender, income, living standard ones), decent work, quality education, cultural diversity, sustainable urbanization, and sustainable life styles
6. **Economic** pillar: resource (raw materials, energy, water, air, land) efficiency and circular economy, affordable and clean energy, sustainable consumption and production, R&D, innovations and entrepreneurship of all stakeholders, and economic de-growth
7. ESD **methodologies**: participatory teaching and learning, student-centered teaching, critical, interdisciplinary, and systems thinking, creativity, and imagining future scenarios (envisioning)
8. **Transformative** teaching, learning and training: holistic approach, digital literacy, infrastructure and environments, developing case studies
9. **Building capacity** for educators and trainers at all levels, media, developing pedagogies, ESD tools, literature, project reports and presentations (PowerPoints, videos, etc.), and financing of projects
10. **ESD metrics**: indicators and indices, sustainability accounting and reporting
11. **ESD documents**: international agreements, declarations, from Agenda 21 to 2030 Agenda for SD
12. **ESD institutions**: UN (UNESCO, UNCED, UNEP, UNECE), EEA/EPA, global and regional associations (IAU, CA), national institutions, and NGOs.

3. Discussion

3.1 ESD Scope

The ESD course shall start with the *definitions* of SD and ESD. It is intended to be taught at all the levels (from primary to tertiary one), including life-long, formal, non-formal and informal education. ESD scope from early events and documents up to modern teaching and learning of SD follows. The key milestones of *ESD* are: Earth Summits in Rio de Janeiro in 1992 (including Agenda 21, Rio Declaration and Conventions), Rio+10 conference in Johannesburg (with first USA boycott; Plan of Implementation, PoI), Rio+20 summit, again in Rio (document

"*The Future We Want*"), The Decade of ESD, and the Global Action Program (GAP) on ESD with the Climate Change Education for SD, and, finally SDGs with the Goal No. 4 on quality education, and the target 4.7 on knowledge about SD, ESD, sustainable lifestyles, human rights, etc.

ESD competences (UNECE, 2012) present essential characteristics of ESD (holistic approach, envisioning change, and achieving transformation), and the framework of learning experiences (learning to know – cognitive domain, learning to do – conative domain, learning to live together – social domain, and learning to be – emotional domain). UNESCO (2017) is citing 8 key competencies for achieving the SDGs: 1) system thinking;
2) anticipatory, 3) normative, and 4) strategic approaches; 5) collaboration, 6) critical thinking, 7) self- awareness, and 8) integrated problem-solving. Competences to address SDGs in higher education need a reflection on the equilibrium between systemic and personal approaches to achieve transformation action (Dlouha et al., 2019).

Quality education shall be inclusive and equitable, and promote learning opportunities for all (SDG 4). It is including quality from early childhood development to secondary education, skills at technical, vocational and tertiary levels, entrepreneurship, and ESD (UN, 2015). The World Economic Forum (WEF, 2015) proposed five key goals: 1) to unleash the infinite potential of humanity, 2) to learn how to apply oneself as an instrument towards lifelong value, 3) to learn how to shape the future, 4) to understand and master the conditions for peace,

and 5) to learn how to be healthy and happy. The World Bank is citing six necessary components (referred to as the *6 A's*) to achieve such reforms: 1) assessment, 2) autonomy, 3) accountability, 4) attentions to teachers, 5) early childhood development, and 5) culture (Patrinos et al., 2014). Six crucial dimensions of quality education are: 1) equity, 2) contextualization and relevance, 3) child-friendly teaching and learning, 4) sustainability, 5) balanced approach, and 6) learning outcomes" (VVOB, 2018). Ng's research (Ng, 2015) indicates that quality education "includes holistic development, equips students with the knowledge and skills for the future, inculcates students with the right values, and imbues students with a positive learning attitude". It is "delivered by good teachers, enabled by good teaching and learning processes, and facilitated by a conductive learning environment". Ofei-Manu and Didham (2014) argue that quality ESD could be improved by: "supporting curriculum towards transformative educational and teaching approaches, strengthening teachers' competency for ESD, guiding school administrators to support experiential education, and encouraging education policy makers to consider transformative learning approaches and the integration of ESD into standard educational policy".

Weak sustainability believes that 'natural capital' can be substituted by 'human capital'; e.g. coal as natural resource can be converted into electricity and used to improve human life. It was developed within the environmental economics by Robert Sollow (1974) and John Hartwick (1977). *Strong sustainability* assumes that both 'capitals' are complementary but not interchangeable – economy is only a subset of society, and society is dependent on the environment (it is often presented in 3 circles, where economy is embraced with by society and society is encircled as being determined by environment). Land, water, air, and biodiversity cannot be substituted. Economy and society are constrained by environmental boundaries – limits to growth (Meadows et al., 1972). Therefore, strong sustainable consumption is about de-growth (Lorek and Fuchs, 2013).

3.1 ESD Policy

ESD vision is a balance between society, economy and environment while preserving the natural resources of our Planet for future generations. The vision of UNESCO (2000) on ESD is to provide learners with the "skills, perspectives, values and knowledge to live sustainably in their communities". An empirical study in Czech

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Republic indicated the vision of ESD learners to be: self-confident, grounded, open, and engaged (Dlouha and Pospišilova, 2018).

ESD *mission* is defined in the SDG 4 with its 7 targets and 3 targeted actions. The mission of ESD in higher education is to make the world a better place to live, and create graduates who are able to contribute to solutions of our urgent societal needs (AASHE, 2017). UNECE (2017) *Strategy* for ESD is to enable the learners for "leading healthy and productive lifestyles in harmony with nature and with concern for social values, gender equity and cultural diversity".

Peace is not just the absence of war or violence but also a pathway to expand human potential without harming others; peace creates conditions for SD (MGIEP, 2014). Violence kills more than 1.6 million people every year (Bhagabati, 2006). In 2015, the cost of violence was estimated to be 13.6 TUSD (trillion US dollars = 10^{12} USD) and is expressed in purchasing power parity (PPP) terms (Schippa, 2017). This is equivalent to 13.3 % of world GDP (Gross Domestic Product) or 1 876 USD/a (per annum) per person or 5 USD/d (per day) per person, every day of the year – World Bank estimates that 10.7 % of the worlds' population are living on less than 2 USD/d. And we spend next to nothing on peace.

ESD started by concentrating on pedagogical approach and environmental problems. Later, *social* matters were also addressed including equality, justice, non-violence, democracy, rule of law, strong institutions, public awareness and participation, power and influence distribution, sustainable communities, cities, regions, nations and countries, population control, etc. The topics were stimulated by the UN documents on MDGs (2000–2015), and SDGs (2016–2030). A typical example of including social responsibility into education is the Sustainable and Socially Responsible University of Maribor (SSRUM, 2018).

3.1 ESD cooperation

Universities shall cooperate with other institutions using United Nations Principles of Responsible Management Education (UN PRME). As a voluntary initiative with over 650 signatories worldwide, PRME has become the largest organized relationship between the UN and management-related higher education institutions. It engages business and management schools to ensure they provide future leaders with the skills needed to balance economic and sustainability goals, while drawing attention to the SDGs and aligning academic institutions with the work of the UN Global Compact (UN GC). The PRME's (2019) *six principles* are: 1) Purpose – students as future generators of inclusive and sustainable global economy, 2) Values – global social responsibility, 3) Method – educational framework, materials, processes and environments that enable effective learning for responsible leadership, 4) Research to create sustainable social, environmental and economic value, 5) Partnership with managers of business corporations, and 6) Dialogue among educators, students, business, government, consumers, media, civil organizations etc.

3.2 Environmental pillar

"The environmental pillar refers to the laws, regulations, and other policy mechanisms concerning air and water pollution, solid waste management, ecosystem management, maintenance of biodiversity, and the protection of natural resources, wildlife and endangered species. Its regional key issues are: climate change, global warming, the environment and human rights (persecution of activists), modern and renewable energy, ecological development (ending natural resource depletion), reversed air pollution and improved water management, and better control of natural resource extraction. Government (national, regional, local, etc.) instruments may include economic incentives and market-based instruments such as taxes and tax exemptions, tradable permits, awareness campaigns and educational activities." (EU Policy Forum, 2019a).

There are many warnings that universities are not doing enough efforts in sustainable development and especially in the approaching climate change disaster. More should be done in informing and engaging staff and students, and leading by example. Universities could be doing much more than they do, including buildings to the highest environmental standards, cutting waste, reducing institutional footprints and banishing plastic from campuses (THE, 2019). Research into climate change and public advocacy role are also very important. Sustainability shall be embedded into learning. Universities in UK (followed by Finland, Canada and USA) are the most environmentally sustainable in the world (SDGs 17, 3, etc.; THE, 2019a), while those in Canada (Australia, Russia and Ireland) are doing the most to tackle climate change (SDG 13); rankings according to other SDGs are also available (THE, 2019b). The Alliance for Sustainability Leadership in Education (EAUC) is proactive in recycling, plastic alternatives, divesting from fossil fuels, and ethical supply chains.

3.3 Social pillar

"The social pillar refers to social issues: our wellbeing (health- and aged care, free education, housing, employment, etc.). They ensure that individuals do have access to social services, do not suffer through lack of knowledge of their rights, and exercise a responsible influence on the development of social policies and services, both locally and nationally. Key regional issues are: poverty eradication or alleviation, security of jobs versus contract labor without benefits, income inequality, health and health care, universal access to sexual and reproductive health services, access to education, biases against women, and need for gender equality (both economic opportunities for women and protection from gender based violence issues)." (EU Policy Forum, 2019b).

UNESCO has shared a draft framework for ESD beyond 2019; its three messages are: a) transformative action of individuals, b) structural change – relationship between economic growth and sustainable development and c) technological future – critical thinking and green skills. The last years have sharpened some social responsibility focal points on SDGs and brought additional tasks for ESD like:

- Decreasing the growing inequalities between 1 % of rich individuals and the 99 % majority
- Exploitation with the rise of precariat on one side, and plutocracy and oligarchy on the other one
- Predominant influence of multinational corporations over policy, jurisdiction, and democracy
- Avoidance of taxation for common good by using different types of tax havens
- Harmful influence of neoliberalism on social market economy, social security, and social justice
- Massive human migrations because of wars and climate changes, and the growth of terrorism
- Nationalism and populism as an unwanted response to those problems.

ESD has to respond to these new challenges of humankind by modifying and focusing its paradigm.
The current economic and social paradigm is "faster, higher, further". It is built on and stimulates competition between all humans. This causes acceleration, stress and exclusion. Our economy destroys the natural basis of life. The common values of de-growth society should be care, solidarity and cooperation. By "de-growth", we understand a form of society and economy which aims at the well-being of all and sustains the natural basis of life.

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To achieve de-growth, we need a fundamental transformation of our lives and an extensive cultural change. Essential for de-growth are (Degrowth, 2019):

- "Striving for the good life for all. This includes deceleration, time welfare and conviviality.
- A reduction of production and consumption in the global North, and liberation from the one-sided Western paradigm of development. This could allow for a self-determined path of social organization in the global South.
- An extension of democratic decision-making to allow for real political participation.
- Social changes and an orientation towards **sufficiency** instead of purely technological changes and improvements in efficiency in order to solve ecological problems. We believe that it has historically been proven that decoupling economic growth from resource use is not possible.
- The creation of open, connected, and localized economies."

3.4 Economic pillar

"The economic pillar includes trade and investment, employment growth, private sector development, domestic and international trends and assets. Its instruments include tax policy, public-private partnerships, trade and employment policies, national and international finance, etc. Key regional issues are: poverty eradication or alleviation, lack of decent and productive jobs, SME development (toward sustainable growth), role and involvement of private sector, employment creation, jobs security versus contract labor without benefits, income inequality, and local economic development. The SDGs are called to include: a living wage indicator, the end of tax havens and tax avoidance, reaching a minimum global corporate tax rate, etc." (EU Policy Forum, 2019c).

Various studies have shown that targets under the Paris Climate Agreement can only be met by developing technologies that will provide 'negative emissions' (Clark et al., 2014) – seen as a questionable strategy (Anderson and Peters, 2016), or that efficiency improvements and low-carbon technologies with projected economic growth will overshoot such targets. It implies that slower growth, or de-growth, particularly in the developed countries, is required to stay within planetary limits (Anderson and Peters, 2016; Koning et al, 2016). Moving towards strong sustainable consumption requires two phases of development (Fuchs and Lorek, 2005):

1) Increase in the efficiency of consumption due to technological improvements (eco-design, sustainable production, eco-innovation, etc.), and due to more efficient use of resources (3R – reduce-reuse- recycle, zero waste, etc.) what is called *weak sustainable consumption (SC).*
2) Changes in consumption patterns (habits, behaviors, and life styles) and reduction in consumption levels (de-growth) in developed countries requiring changes in infrastructures what is called *strong SC.*

Weak SC may be e.g. using a car with a reduced gasoline usage of 3 cl/km (3 liters per 100 km) while strong SC means using public transportation instead of the car. People (individuals, businesses, and governments) are ready to apply the first phase but they are hesitant to use the second one.

The main causes of overconsumption are mobility (car and air transport including holiday trips), food (meat, diary, obesity), energy use (heating, cooling, energy using appliances), and housing (building and demolition) which are causing 70–80 % of the life-cycle environmental impact categories (Tukker et al., 2008b). OECD countries have 19 % of human population but consume 80 % of the global resources.

3.1 ESD Methodologies

"Pedagogy describes the practice or method of teaching (Green Office, 2019). Different to the teaching content, it does not describe *what* students learn, but *how* they learn". "The two most commonly discussed principles are active learning and student-centered learning. Progress has also taken place at the teaching method level, with the development of collaborative learning, experiential learning, and problem-based learning" (Slavich & Zimbardo, 2012). An interactive, experiential, learner-centered, and action-oriented pedagogy is the third element of ESD. Students should work collaboratively on group assignments, solve real-life problems for an external client, go on excursions or discuss problems in small group seminars. The teacher is rather a facilitator than knowledge provider. The student is rather active and responsibl, than being a passive recipient of knowledge.

Teaching methods are "adapted to the audience, to learning objectives and to content"**.** *Participatory teaching* is using student-centered learning which can include "flipped classrooms, case studies, problem solving, mini-projects, short-term tasks, formal presentations, debates, panel discussions, tutorials, practical work sessions, workshops, role-play, multimedia sessions, simulations, study visits, blended learning, etc. The more interactive and participatory the method, the greater the audience's concentration and the easier skills are acquired"

(INSTN, 2019). Case studies can be found at the Leading Practice Publication (UE4SD Platform, 2016). Many massive open online courses (MOOCs) are available.

3.2 Transformative teaching, learning and training

"Transformative or transformational teaching changes people, altering fundamentally the way learners understand themselves and others, the way they engage in and contribute to their larger world (Briggs, 2015). Slavich and Zimbardo (2012) present six core methods of transformational teaching that reflect this notion:

1. Establishing a shared vision for a course.
2. Providing modeling and mastery experiences.
3. Intellectually challenging and encouraging students.
4. Personalizing attention and feedback.
5. Creating experiential lessons.
6. Promoting pre-flection and reflection.

Transformational teaching is about employing strategies that promote positive changes in students' lives. The goal is not simply to impart certain information to students, but rather to change something about how students learn and live. It is about making lifelong changes."

"As a guide, Slavich proposes the following parameters for measuring transformational teaching (Briggs, 2015):

1. The teacher is conceptualized as an instructor of the relevant material and also as a change agent who guides students through the transformational process.
2. In his or her role as change agent, the teacher works to decrease students' perceived barriers to success while increasing their self-efficacy for change.
3. Teaching centers on the use of self-change projects but requires previous mastery of the course concepts via other teaching methods.
4. Students are viewed as being capable of mastering the course content and achieving the targeted changes."

"Inquiry-based learning, service learning, and project-based learning are all forms of transformational education" (Fuglei, 2014). Teachers who use these methods have a high burden of preparation and flexibility, but the short-

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term time investment has long-term payoff, particularly when a classroom of learners becomes an engaged community capable of reflecting on their needs and interests. Key aspects of transformational teaching are: active learning, collaboration and persistence. Active classrooms sometimes require collaborative or team- based work. When students leave the classroom, they will be engaged in a work world that frequently requires group work or someone to act as a team leader. Another key aspect of transformational teaching is the concept of struggle. Recent educational research looks to long-term student success and has identified one of the key traits among those with the highest educational success as persistence. Struggle and failure is part of the learning process."

Teaching creativity is very important, too. It is "hands-on, participative and experiential, and requires a model that encourages the students to be entrepreneurial and become producers rather than consumers of information. It is also about learning how to communicate in the digital space, having the ability to understand information systems, evaluate data and identify fake news" (Taylor, 2019).

3.3 Building capacity

Building capacity (also capacity building or capacity development) is "the process by which individuals and organizations obtain, improve, and retain the skills, knowledge, tools, equipment and other resources needed to do their jobs competently. It also allows individuals and organizations perform at a greater capacity (larger scale, larger audience, larger impact, etc.)" (Potter and Brough, 2004).

Erasmus+ project *University Educators for Sustainable Development* (UE4SD, 2016) has tried to re-orient the HE curriculum towards SD by improving support for university educators to develop professional competences in ESD. It is suitable for all levels of education and also for other jobs in HEIs and in SD. *Professional Development* recognizes that change is a constant feature of life. It addresses the need for continual learning and conscious reflection to respond effectively to change in professional practice. This can be supported through informal or formal activities, such as training, mentoring, workshops, action-learning sets, workplace projects and accreditation schemes. Developing academic leadership and the ability to influence and change the way the curriculum is shaped is very important nowadays. The State of the Art report found that many European countries lack formal ESD professional development opportunities. An Academy was initiated and its pilot program prepared to fil in the gap. It brings a range of professional challenges to the university educator, such as (see the UE4SD online resource platform):

- Understanding how new pedagogies could be applied in their subject
- Linking ESD pedagogies with the special literacies (science, reading, and mathematics) they teach
- Reframing what quality learning outcomes might look like with ESD
- Engaging with students in different ways in the learning relationship
- Digesting new sustainability thinking and practice in their industry/profession
- Learning more about how to achieve education change in their workplace.

A current Erasmus+ project on Education for Zero Waste and Circular Economy is developing online courses for two interdisciplinary jobs: manager or teacher, and technician or worker (EduZWaCE, 2018). It is including also the Knowledge Hub, Platform, Diagnosis tool, and Dissemination as intellectual outputs. Further Erasmus+ (2019) and former program projects overview is available.

3.4 ESD metrics

Quality of education is normally measured in the following three dimensions: 1) Reading and language proficiency, 2) Mathematics and numeracy proficiency, and 3) Scientific knowledge and understanding. The Program for international Student Assessment (PISA – science, reading and mathematics literacies), Progress in International Reading Literacy Study (PIRLS), Trends in International Mathematics and Science Study (TIMSS), and Program for the International Assessment of Adult Competencies (PIAAC) are the most often used evaluations. In tertiary education (TE) the share of population with TE, enrolment in TE, school life expectancy to TE, international mobility of students, etc. are measured and published.

Schools from primary to tertiary levels and campuses can measure and mutually compare their environmental impact by four popular metrics: carbon emissions, water use, recycling rate, and energy use as well as health status and financial input per capita. More seldom is to measure and compare other social and economic indicators: poverty and hunger, wellbeing, equalities, peace and justice, etc. Many indices are available for universities but they are mainly concerned with research and development (R&D) activities. *GreenMetric* (2018) is comparing universities regarding their environmental achievements: 1) campus setting and infrastructure, 2) energy and climate change, 3) waste, 4) water, and 5) transportation.

THE (2019) *University Impact Rankings* measure global universities' success in delivering the UN SDGs across three broad areas: research**,** outreach, and stewardship. 11 out of 17 SDGs are included. Universities can submit data on as many of these SDGs as they are able. Each SDG has a series of metrics that are used to evaluate the performance of the university in that SDG. Any university that provides data on SDG 17 (Partnerships for the Goals) and at least three other SDGs is included in the overall ranking. Besides the overall ranking, the results of each individual SDG are also published in 11 separate tables. A university's final score in the overall table is calculated by combining its score in SDG 17 with its top three scores out of the remaining 10 SDGs. SDG 17 accounts for 22 % of the overall score, while the other SDGs carry a weighting of 26 % each. There are three categories of metrics within each SDG: research (metrics are derived from data supplied by Elsevier), continuous metric (contributions to impact that vary continually across a range – for example, the number of graduates with a health-related degree) and evidence to support the claims.

Universities have significant influence on a large proportion of the world's future leaders. Reporting, managing, engaging and developing strategy on SD issues therefore stands to have considerable impact (Adams, 2018). The way the students are educated can be a force for change. Yet, despite the 22 years of developments in sustainability reporting and the 7 years of integrated reporting, this potential is not exploited enough.

3.5 ESD Documents

The most important ESD documents that help the reader find additional information are:

- Education for Sustainable Development Toolkit (McKeown, 2006)
- Teachers' Guide for Education for Sustainable Development in the Caribbean (Cambers et al., 2008)
- The Competences in ESD (Learning for the Future Competences) (UNECE, 2012)
- Sustainable development in higher education (HEFCE, 2014)
- ESD and the Quality Management and Enhancement Framework (Longhurst, 2014)
- Shaping the Future We Want, UN Decade of ESD, Final Report (UNESCO, 2014)

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- Transformative Teaching: Changing Today's Classrooms … (Kryza, 2015)
- Building Capacity in Higher Education Topic Guide (HEART, 2015)
- Education and the SDGs, Educate a Child (EAC and FHI 360, 2016)
- Transformative Teachers; Teacher Leadership and Learning in a Connected World (Baker-Doyle, 2017)
- Education for Sustainable Development. Learning Objectives (UNESCO, 2017)
- Consultation on Further and Higher Education and the SDGs (EAUC, 2018)
- Issues and trends in Education for Sustainable Development, (UNESCO, 2018).

Further documents can be found at the UE4SD Platform (2016) – Useful Publications with three resource packages: 1) International ESD Initiatives, 2) European ESD Policy and Guidance, and 3) ESD and Professional Development.

3.6 ESD institutions

United Nations (UN) maintains many organizations dealing with the ESD. The most known one is *UNESCO*, United Nations Educational, Scientific and Cultural Organization; its platform has links to ESD definition, the work going on, resources (including key publications, Overview of the International Frameworks on ESD, and HESI Higher Education Sustainability Initiative), and the future of ESD. *UNEP*, United Nations Environment Program platform is including: Education for Sustainable Consumption, Sustainability communications: A Toolkit for Marketing and Advertising Courses, Shaping the Future We Want – UN Decade of Education for Sustainable Development (DESD, Final report), The International Training Program on **ESD** in Higher Education (ITP ESD-HE), Environmental Education for SDGs, etc. *UNECE*, The United Nations Economic Commission for Europe has published: the Evaluation report on the implementation of the UNECE strategy for ESD 2005–2015, Empowering Educators, Competences for ESD and other contributions.

The *European Environment Agency* (EEA) is helping the Community and its member states to make informed decisions about improving the environment, integrating environmental considerations into economic policies and moving towards sustainability. It is publishing a 5-years State and outlook of the European environment (SOER) as well as global megatrends and cross-country comparisons. The European Network of the Heads of Environment Protection Agencies (EPA Network) deals with the implementation of environmental policy and communication of environmental issues. The European environment information and observation network (Eionet) is a partnership network of the EEA, and its 33 member- and 6 cooperating countries.

International Association of Universities (IAU), created under the auspices of UNESCO in 1950 provides a framework for universities to develop inter-institutional collaboration in pursuit of SD. IAU (2019a) developed **a** dedicated portal on Higher Education and Research for Sustainable Development including all the SDGs. IAU (2019b) has just published an overview on climate action (SDG 13). 169 actions are listed under the SDG 4. The *COPERNICUS Alliance* (CA, 2019) is a European network of universities and colleges committed to transformational learning and change for SD. CA is organizing face to face and online annual conferences on HESD, participates in R&D projects, and awards micro funds. *The Association for the Advancement of Sustainability in Higher Education* (AASHE) has over 900 members across 48 U.S. states, 9 Canadian provinces and 20 countries. It is publishing news, the Bulletin, annual reports, and its Hub contains over 1000 publications.

Non-governmental organizations (NGOs) and National institutions are important, too. The UN Economic and Social

Council (ECOSOC, 2018) is listing over 4900 NGOs with consultative status. It is the principal body for the coordination, policy review, policy dialogue and recommendations on issues of economic and social development including the SDGs. Many NGOs are dealing with SD, some of them also with ESD. For example, Gaia Education (2019) is an international NGO which provides students of all ages and cultural backgrounds in 54 countries with knowledge and skills to design a thriving society. A list of face to face and e-learning programs is available. Links between HE organizations and NGOs promote ESD (Haigh, 2006). Similarly, the purpose of the NGO Committee on Sustainable Development-NY (NGOCSD, 2019) is to monitor and influence the implementation of the commitments and agreements adopted by the United Nations that pertain to sustainable development, from 1992 Rio Earth Summit to UN SDGs (SDG Education Alliance).

4. Conclusions

The latest data on SD are below the expected ones. The climate change is turning into the climate crisis. Climate disasters are increasing both in frequency and severity. Let us mention some of them: heat waves with draughts, wildfires, reduced food production, ice and permafrost melting with methane release, and water scarcity. July 2019 was the hottest month ever and the heat wave in Western Europe; vast areas of the Arctic (Russia, Greenland, Canada and Alaska), and the Amazon rainforest were in flames. On the other side thunderstorms, hurricanes, tornados, cyclones, floods and avalanches are destroying fertile land, settlements and people's lives. In 2018 alone, 17.2 million new displacements associated with disasters in 148 countries and territories were recorded; The World Bank estimated that as many as 143 million people in sub-Saharan Africa, South Asia, and Latin America could become climate migrants by 2050. The World Health Organization (WHO) estimated that climate crisis would lead to about 250 000 additional deaths each year. Global bio-diversity loss is estimated to be 100–1000 times higher than the (naturally occurring) background extinction rate and it is expected to still grow in the upcoming years. We already know that the Paris Agreement to keep a global temperature rise this century well below 2 °C above pre-industrial levels will not be enough (even without the USA and Brazil withdrawals from the Agreement). The hysteresis effect is further worsening the future development of humanity.

The social pillar development is not much better. Although the share of people living in poverty and hunger has decreased in the last decades, the non-equalities between the richest 1 % and 99 % poor are increasing rapidly. But, the World population and per capita consumption are increasing. The wars are persisting and spread out to new regions. Present and future climate migrants are causing severe problems in developed countries strengthening nationalists' political parties and leading potentially to third World war. The neoliberal economic system is causing these changes by requiring constant GDP growth and free market domination with diminishing role of the social state. The raw materials scarcity, the renewable energy production, and the limited Planet cannot cope with such an extensive growth. But people, businesses and governments in developed countries are hesitating to change their lifestyles, management and social models.

To decrease consumption, de-growth and life style changes are needed in developed countries. Profound changes in human mind are required to achieve de-growth. Education can and has to play the most important role in this development change. Universities are not doing enough efforts in sustainable development and in the climate change disaster prevention. The Happy Planet Index (HPI, 2016) peaks at 5 kUSD (thousand) GDP per capita while developed nations achieve 30–40 kUSD, South European and wealthy East Asian countries about 25 kUSD, and Gulf and new EU member states around 15 kUSD. The above described 12 key issues of ESD are just the beginning

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of the new age – they need constant updating and revolutionary changes. Greta Thunberg and 1.4 million students in 112 countries have required them.

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Acronyms and abbreviations

CA Copernicus Alliance
EAUC Environmental Association for Universities and Colleges
ESD Education *for* Sustainable Development
EU European Union
GAP Global Action Programme
HEI Higher education institution
HESD Higher Education for Sustainable Development
IAU International Association of Universities
MDGs Millennium Development Goals
NGO Non-governmental organization
OECD Organisation for Economic Co-operation and Development
SC Sustainable Consumption
SD Sustainable Development SDGsSustainable Development Goals
THE Times Higher Education
UE4SD University Educators for Sustainable Development
UN United Nations
UNCED UN Conference on Environment & Development
UNECE United Nations Economic Commission for Europe
UNEP UN Education Program
UNESCO United Nations Educational, Scientific and Cultural Organization
WCED World Commission on Environment and Development

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Selection and Framing of Briefs for Circular Design Students Projects

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Abstract
Developing a successful design brief that tackles the current growing environmental problems, challenges the current dominant systems and enables circular solutions is a complex task. Briefs are an integral step for framing the design projects and they require a systemic approach to facilitate desired sustainable outcomes from projects. While there are studies exploring the preparation of successful briefs, there aren't many that focus on design brief development in circular economy education. This paper examines the design brief formulation process of eleven product design projects from four consecutive training programmes in four European universities in collaboration with sixteen companies. These eleven projects were developed for the Circular Design Internships conducted as a part of the Learning for Innovative Design for Sustainability (L4IDS) Erasmus+ Knowledge Alliance project. L4IDS project aims to create better learning environments for the circular economy in universities and enterprises. In this paper, developing briefs is regarded as a creative process aiming to provide a guide to support students and enable effective learning, facilitate creativity and inspire innovation for the circular economy. Throughout the four internships, the brief development process has evolved together with the internship structure based on the data collected and feedback provided to the subsequent internships by the previous ones. Extended schedules including reflections of internship supervisors, evaluations of interns and companies were one of the methods used to deliver effective feedback. Considering the brief making process of these eleven design projects, the five main steps of brief making for circular design were identified including reviewing the existing resources, emphasising the importance of systems thinking in a circular economy while defining the objectives, selecting the industry partner and emphasizing the importance of collaboration for the circular economy, focusing on circularity during the detailing, and communicating expectations. Finally, the paper outlines how design briefs changed throughout the consecutive internships according to the different structures of the four education programmes. Then, it will discuss the characteristics of the circular design briefs and preparing an adaptable brief conforming to the structures of various universities. As a result, suggestions on how to develop design briefs for the circular economy are presented. Although it is not possible to design a brief template applicable to all kinds of projects, the outcomes of this paper could be used to create a guide for preparing design briefs for the circular economy.

Keywords: Design Brief, Design Education, Circular Economy, Product Design

1. Introduction

Design briefs are an integral part of design education, especially for project-based modules, outlining a starting point of the educational design projects and hinting at the learning outcomes for novice designers. In the context of a collaboration between industry partners and a higher education institution in the area of design for sustainability and circular economy, the design briefs require an integrated approach. This approach should consider various requirements of the collaborating partners, a wide scope of sustainability and circular economy theories and challenges. While there are studies on integrating concerns of sustainability into design briefs (e.g. Dewulf et al., 2012), there are not many studies about the educational design projects.

This paper presents the development of design briefs for four consecutive Circular Design Internships facilitated in Ireland, Spain, the Netherlands, and Sweden. This internship programme was developed as part of the Learning for Innovative Design for Sustainability (L4IDS) Erasmus+ Knowledge Alliance project, with four European institutions with design departments [University of Limerick (UL) in Ireland, Universitat Politècnica de Catalunya (UPC) in Spain, NHL University of Applied Sciences (NHL) in the Netherlands, and Linköping University (LiU) in Sweden along with four design-led SMEs (Small to Medium Enterprises) and three National Design Agencies]. One of the purposes of the L4IDS E+KA project is to develop an exchange training programme for circular design with an adaptable schedule conforming to the structures of these schools. The aim of the programme is to promote a culturally diverse, interdisciplinary working environment for students from varying backgrounds (i.e. Product Design, Business, Materials Science). The learning outcomes of the internship were identified as:

- Creating the environment for interns *to self-learn and experience* the necessary tools and techniques for circular design.
- Facilitating learning for innovative, sustainable design *for both the interns and the industry partners* throughout the design process.
- Present the potential of innovative design tools and techniques for sustainability and circular economy as applied to *real-life innovation processes* (Bakirlioglu et al., 2018, McMahon and Bakirlioglu, 2019).

The structure of the internship programme and its effects on the practices of industry partners are presented elsewhere (Bakirlioglu et al., 2018, McMahon and Bakirlioglu, 2019). This paper introduces these differences and how design briefs incorporated sustainability and circular economy in different contexts. 11 design briefs for these internships were developed in collaboration with 16 local industry partners in the four partner countries, and their content has changed to adapt not only to the different educational approaches of partner universities but also to the industry partners' processes, resources, knowledge, and experience.

2. Background

The role of higher education institutions to initiate change towards sustainability was discussed widely through capacity building (e.g. O'Rafferty et al., 2014; Lozano, 2006), changes in learning outcomes (e.g. Shephard, 2008), and facilitating change in practice (e.g. Zilahy and Huisingh, 2009). However, there are barriers for integrating sustainability in all levels of education (Sterling and Witham, 2008; Boks and Diehl, 2006; de Eyto, 2010) as well as influencing the adoption of these concerns in real-life design processes (McMahon and Bakirlioglu, 2019; Bakirlioglu et al., 2018). Mainstreaming sustainability throughout third-level design education and integrating principles of sustainability and its design-related competencies present potentials in deep learning over an extended

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period and ready future designers for sustainability challenges ahead (O'Rafferty et al., 2014; de Eyto et al., 2008). For industry currently in business and in need of or desire to change their practices, higher education institutions can act as intermediaries through utilizing the expertise of academics on design for sustainability (Küçüksayraç et al., 2017). The Circular Design Internship programme adopts an integrated approach, where knowledge exchange among researchers/educators, industry partners, and novice designers are facilitated through in a collaborative and multi-cultural setting. As the initiator of this collaborative learning environment, design briefs were important tools, and they were adapted throughout the four implementations of this internship programme.

Design briefs in the past adopted a rather mechanistic perspective (Blyth and Worthington, 2001), with the problem, process and expected outcomes clearly defined as much as possible. However, this perspective has changed, and developing briefs is now considered to be an integral part of the design process – rather than just the starting point (Dewulf et al., 2012). Design briefs framed in a more abstract manner can result in a divergence of ideas, as opposed to more concrete briefs with strictly identified constraints (Zahner et al., 2010). According to Phillips (2004), design briefs consist of 7 elements and an optional *appendix*. *Project overview & background* can be considered as a summary articulating the scope, objectives and desired outcomes. *Category review* is the examination of the clients' industry. *The Target audience* refers to the audience of the design solution. The activities of the company are explained in *the company portfolio*, followed by its *business objectives and design strategy*. *Project scope, timeline, and budget* provide an overview of project phases and their monetary and time constraints.

While this list of elements provides a good starting point for formulating a brief, some elements can be purposely left abstract in educational contexts, with the purpose of novice designers gain experience in defining problems and better scoping of design projects. Partially defined problem and solution areas can co-evolve throughout a design project (Maher and Poon, 1996). The constraints of the design brief are identified according to the expected learning outcomes in the context of design education, however, the internship programme in question attempts to reconcile the learning outcomes intended by educators and expected for the interns, as well as the expectations of industry partners.

3. Methods

Circular Design Internship programme was created by four higher education institutions in four different EU countries. Eleven circular design briefs were developed and turned into projects in collaboration with sixteen industry partners in four design departments. All four of these design departments adopt a practice-based learning approach in a studio environment, however, the structuring of their curriculum and content varies greatly. Hence, interns participating in the internship programme from different institutions generally have different competencies of or approaches to design, which affects the structure and the content of the internship programme. These institutions agreed upon adopting a collaborative action research framework in Figure 1, to reflect on and build upon the previous implementation of the programme, and to provide reflections and guidance for the subsequent implementation. Collaborative action research is utilized to bring together lecturers, human resources and researchers to improve pedagogical practice and contribute to educational theory (Oja and Smulyan, 1989). In the case of Circular Design Internship, different institutions from different cultural backgrounds and pedagogical perspectives are involved and the development of the programme requires reflection of the involved researchers on the existing design education.

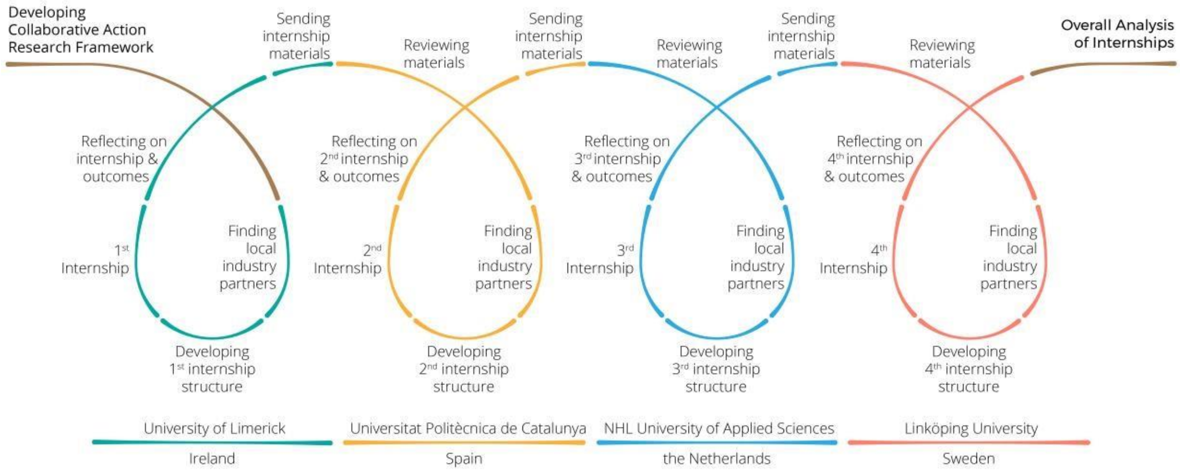

Figure 1. *Collaborative Action Research Framework developed in Learning for Innovative Design for Sustainability Erasmus+ project, indicating the internship cycles (adapted from Bakirlioglu et al., 2018).*

The knowledge exchange among design educators was facilitated through a cloud-based folder, *Circular Design Internship Pack*, which included (1) design briefs, (2) masterclasses, workshops and assignments, (3) relevant visual materials, (4) internship outcomes, (5) feedback gathering materials and (6) an extended schedule with reflections. For the first internship at the University of Limerick, Ireland, the researcher/educators developed the first instances of design briefs with their local industry partners, and scheduled group discussions with interns in intervals throughout the internship. The UL team then analysed these group discussions and prepared an extended schedule with reflections on every step of the programme. This procedure was adopted by the subsequent internship teams, building upon the previous material, improving it and adapting it to their design education approaches, while at the same time generating data on four different instances of this internship programme. This data, other mentioned internship materials and field notes of internship supervisors were collected and analysed to explore the brief development process for circular design. Hence, based on the brief making process of the eleven circular design projects, the main steps for brief making for circular design were identified including reviewing the existing resources, defining objectives, selecting the industry partner, detailing and communicating expectations. The digital versions of these eleven briefs can be found in the L4IDS project website: http://circulardesigneurope.eu/.

4. The Main Steps of the Brief Development for Circular Design

4.1. Reviewing the Existing Resources Related to the Circular Economy

Reviewing relevant existing resources is the first step of brief preparation. These resources could be previous courses, assignments, projects or design competitions prepared with a similar purpose or about the same subject area. In the L4IDS project, the UL team reviewed Open Educational Resources, their courses, assignments, and projects initially to prepare the first set of briefs for the first internship. Open Educational Resources is a website developed as a part of the L4IDS project. It consists of resources and materials about the circular economy and sustainability as well as theories, tools, and methods that can be used at different stages of the design process. After the first internship, each subsequent university partner, reviewed the materials of the previous internships including

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their briefs, extended schedule, supervisor reports, and the final projects, etc., before the process of brief preparation starts. The aim of this was to improve the subsequent internship by reflecting on the previous experiences and to explore other educational tools and techniques for circular design.

4.2. Emphasising the Importance of Systems Thinking in a Circular Economy While Defining the Objectives

Defining objectives is a key step in the brief development process which would clarify the desired outcomes to be achieved through the resulting design solutions. Depending on the overall goal of the project, it could be done with the main partners. However, clarity of the objectives is crucial with the partners and participants.

Although there were some objectives specific to each university partner, all of them took over and embraced the main objectives of the internship:

- Focusing on environmental problems, circular design solutions and emphasising the importance of systems thinking.
- Creating an environment for interns to self-learn.
- Enabling interns to learn and implement the tools for circular design.
- Bringing students and industry partners together in a real-life challenge.

The circular economy cannot be realized without systems thinking. All the actors in the system including designers and manufacturers should focus on optimising the whole system rather than the product or financial gain. All university partners incorporated systems thinking into the internship process. For example, UL’s objective was to define three different scales – i.e. material exploration, product-service system and local/city-scale – as starting points for each project brief and prime the interns to explore the other scales throughout the project. On the other hand, the NHL’s objective was to specifically start the process by introducing interns to systems thinking. As the interns have never studied on a circular design project before the idea behind this was to make it easier for them to understand how things are connected on a meta-level, before working with specific design aspects of such systems.

4.3. Selecting the Industry Partner and Emphasizing the Importance of Collaboration for the Circular Economy

In a circular design project, it is important to choose industry partners who are enthusiastic about the circular economy and open to sustainable solutions that can inform and transform business practices. Each industry partner was chosen from different sectors to provide a diverse range of projects for the mobility scheme (Table 1).

Circular products cannot be created in isolation, nor can they keep being circular in isolation. Actors in a circular system are dependent on each other to close the material loops. This requires cooperation within the companies and between the stakeholders. For instance, working together to reduce waste and increase resource efficiency can be given examples of the benefits of collaboration. To emphasize the importance of collaboration on a circular economy, we have provided some of the existing stakeholders in the area and encouraged students to visit them (Figure 2).

Table 1. *The list of industry partners chosen from different sectors.*

University partner	Industry partner	Industry sector
UL	Mamukko	Craft-producer company
	One Off	Furniture design consultancy
	Southern Region Waste Management Office	Government institution
UPC	ENT	Environment and management consultancy
	UPC Recircula	A project that promotes the circular economy Universitat Politècnica de Catalunya
	ZICLA	Producing solutions for cities with recycled products
NHL	Municipality of Leeuwarden	Government institution
	LIMM Recycling	Recycling
	Lankhorst Engineered Products	Plastic products
LiU	Saiibo	Textiles - workwear
	Tricircular AB, El-Kretsen, Neptunia Invest AB, Tiranious AB, Electrolux, Stena Recycling	White goods recycling

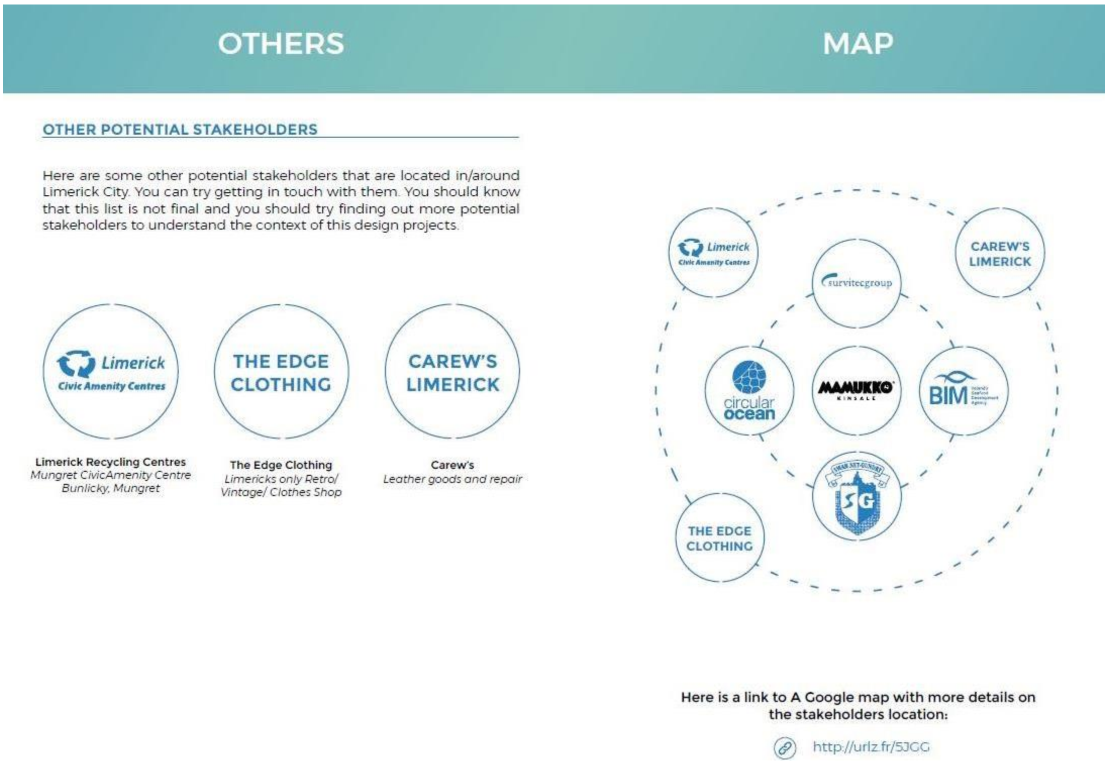

Figure 2*. The potential stakeholders in the area were identified and listed/mapped on the brief to emphasize the importance of collaboration on a circular economy and encourage students to visit them.*

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Ease of accessibility was an important consideration while selecting industry partners, to enable regular partner meetings between the interns and the partner companies. For the internship in Ireland, not all the partners were in Limerick County, however, the interns were provided with detailed information on transportation opportunities. The locality was another aspect that was preferred while choosing industry partners. In the case of the NHL internship, all the partners were local companies from the Fryslan area. This not only enabled the interns to visit the company regularly and be in touch with the client during the projects but also allowed interns to develop sustainable solutions for the local reality they are in. The personal networks of researchers and professors played a big role in finding contact persons to approach potential industry partners, like the companies they have collaborated before in educational or research projects. Since the focus of the internship was circularity, it was important that the companies provided a real problem on this topic. But instead of directly asking for an assignment, the assignments were slowly formed, and the briefs were developed together with the industry partners.

Based on the criteria discussed above, some industry partners were selected. Here are the steps that were taken to approach the industry partners after deciding which ones to work with:

1. The first contact was made through phone or email to explain the L4IDS project including the internship structure and aim. Then brief information was provided about the educational background of the interns.
2. A face to face meeting was arranged with the clients. The purpose of the meeting was to discuss details of the assignments and the expectations from the interns, as well as understanding their company portfolios and facilities/resources.
3. A draft brief was created and presented to the industry partners to initiate constructive discussions and reach a consensus.
4. The industry partners were informed about the programme structure.
5. The detailed project schedule was shared with the industry partners before the internship started.

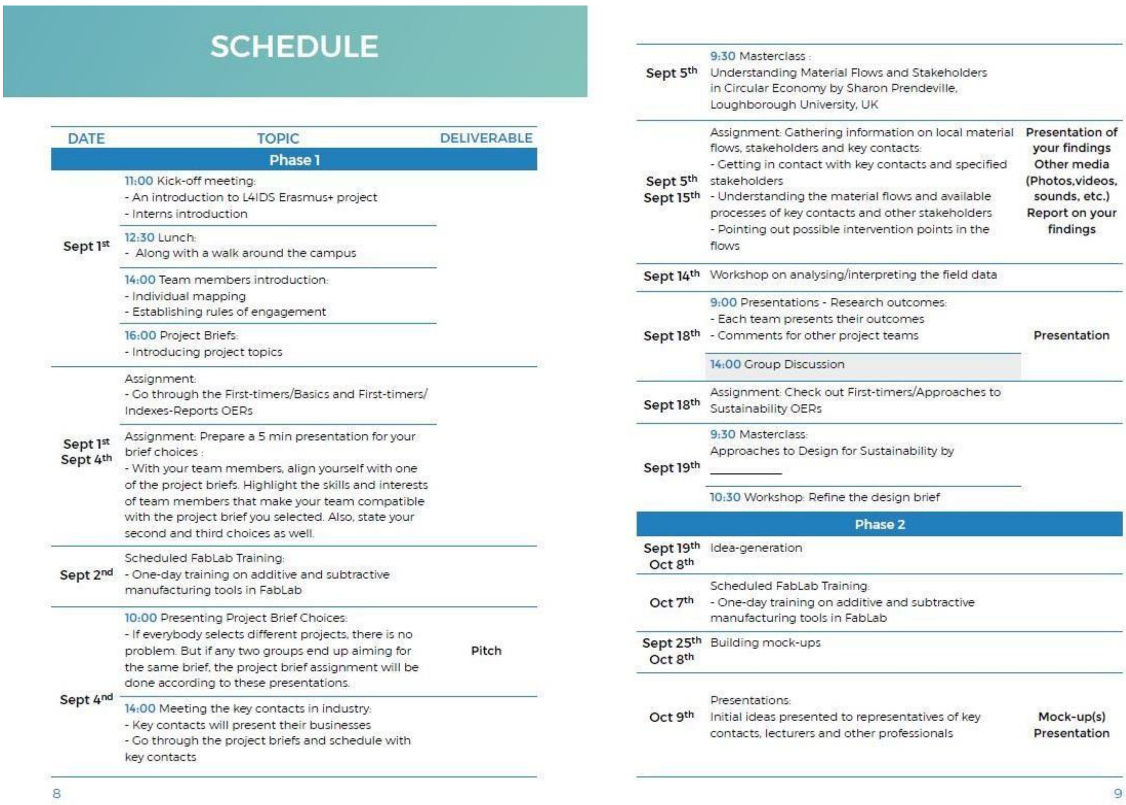
4.4. Focusing on the Inevitability of Circularity During the Detailing Process

This phase corresponds to defining the details of the brief and writing the final brief document. As all the ideas generated from the beginning of the brief development process are refined into the content of the brief, it is crucial to keep the focus on circularity at this stage. In circular design briefs, circularity should be considered as inevitable, not as an add on feature of products or services. The project's objectives, interns' knowledge, and capability were other primary considerations that determined the content.

Content of the briefs:

- The one-sentence objective was included as a quick introduction.
- Description of the assignment.
- Challenges: General challenges of the project were presented in this section, outlining a problem definition formulated along with the industry partners. When formulating the design briefs, it is essential to identify challenges that participants find relevant and meaningful (Sosa et al., 2018). Accordingly, this section also included challenges specific to the industry partner.

- Potential stakeholders in the area: Collaboration within organisations and between the stakeholders is crucial in a circular economy as explained above. In order to kickstart the research phase and meetings, potential stakeholders in the area were identified and listed/mapped on the brief. An example of the stakeholder map that UL prepared can be seen in Figure 2.
- Information about the industry partner and contact details.
- Deliverables (expected outcome): The deliverables were identified based on the problems or opportunities that the project intends to solve or satisfy. What was expected from the interns and how this would be presented were explained in the brief. The deliverables included a process book, final presentation, and prototype.
- Masterclasses, workshops, and resources: Masterclasses and workshops were scheduled according to the possible needs of interns arising at different stages of the internship. The guest lecturers were identified in the brief, as well as the topic of their masterclasses. There were sustainability-specific masterclasses as well as general upskilling-oriented ones. Besides, for every stage of the process, possible Open Educational Resources they can use were identified.
- Schedule: A detailed schedule outlining all the deadlines, resources, deliverables, scheduled meetings and holidays were prepared. An example of the schedule that UL prepared can be seen in Figure 3.
- Practical information about the country and the city: In addition to project-related info, the basic information related to the country and the city were provided to help interns find their way around.



SCHEDULE

DATE	TOPIC	DELIVERABLE
Phase 1		
Sept 1st	11:00 Kick-off meeting: - An introduction to L4IDS Erasmus+ project - Interns introduction	
	12:30 Lunch: - Along with a walk around the campus	
	14:00 Team members introduction: - Individual mapping - Establishing rules of engagement	
	16:00 Project Briefs: - Introducing project topics	
Sept 1st Sept 4th	Assignment: - Go through the First-timers/Basics and First-timers/ Indexes-Reports OERs	
	Assignment: Prepare a 5 min presentation for your brief choices : - With your team members, align yourself with one of the project briefs. Highlight the skills and interests of team members that make your team compatible with the project brief you selected. Also, state your second and third choices as well.	
Sept 2nd	Scheduled FabLab Training: - One-day training on additive and subtractive manufacturing tools in FabLab	
Sept 4nd	10:00 Presenting Project Brief Choices: - If everybody selects different projects, there is no problem. But if any two groups end up aiming for the same brief, the project brief assignment will be done according to these presentations.	**Pitch**
	14:00 Meeting the key contacts in industry: - Key contacts will present their businesses - Go through the project briefs and schedule with key contacts	
Sept 5th	9:30 Masterclass : Understanding Material Flows and Stakeholders in Circular Economy by Sharon Prendeville, Loughborough University, UK	
Sept 5th Sept 15th	Assignment: Gathering information on local material flows, stakeholders and key contacts: - Getting in contact with key contacts and specified stakeholders - Understanding the material flows and available processes of key contacts and other stakeholders - Pointing out possible intervention points in the flows	**Presentation of your findings Other media (Photos,videos, sounds, etc.) Report on your findings**
Sept 14th	Workshop on analysing/interpreting the field data	
Sept 18th	9:00 Presentations - Research outcomes: - Each team presents their outcomes - Comments for other project teams	**Presentation**
	14:00 Group Discussion	
Sept 18th	Assignment: Check out First-timers/Approaches to Sustainability OERs	
Sept 19th	9:30 Masterclass: Approaches to Design for Sustainability by ____________	
	10:30 Workshop: Refine the design brief	
Phase 2		
Sept 19th Oct 8th	Idea-generation	
Oct 7th	Scheduled FabLab Training: - One-day training on additive and subtractive manufacturing tools in FabLab	
Sept 25th Oct 8th	Building mock-ups	
Oct 9th	Presentations: Initial ideas presented to representatives of key contacts, lecturers and other professionals	**Mock-up(s) Presentation**

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***Figure 3**. A detailed schedule outlining all the deadlines, resources, deliverables, scheduled meetings and holidays were prepared.*

4.5. Communicating Expectations

Communicating expectations in a clear way is a key process for dealing with the aspirations of clients (i.e. industry partners). What the clients should expect from this project was explained in detail when we initially approached them, discussing the overall objectives of the internship programme, the duration of the internship, the scope of educational projects and the potential deliverables.

Some of the industry partners were not familiar with the product design education and the studio environment. As they were informed about the nature of an education project, most of them did not have out of context expectations. However, this should be kept in mind that the industry partners did not financially support the project, so they were different than a real-world client. One example of disagreement was seen at the beginning of the NHL internship. The clients struggled with understanding and accepting the systems approach. They preferred a new product concept design rather than exploring its relation to society, environment or physical space.

However, as the project progressed, they were satisfied with the quality and detail of the outcome. The expectations of the industry partners also affected the roles they adopted throughout the internship, while some regarded the intern teams as collaborators, others positioned themselves as mentors. Some of these roles were discussed in detail through interviews conducted with the industry partners of the first internship after one year of its completion (McMahon and Bakirlioglu, 2019).

5. Design Briefs Throughout the Four Consecutive Internships

The design briefs changed throughout the consecutive internships conforming to the education programmes in the four different universities. Table 2 presents these differences between the four internship structures. The previous internships had been the main reference during the brief development process. Extended schedules were primarily used to transfer our experience. Additionally, we reviewed other materials including the briefs, supervisor reports, the final projects and had skype meetings with the previous internship supervisors.

An extended schedule is an improved version of the actual schedule of the assignment. In addition to the date and the title of the activities, it explains the content of each activity and the supervisors' reflection in detail. A critical approach was taken towards each project to be able to identify potential areas of improvement. Although successful parts and failures were expressed openly in extended schedules this resulted in small scale improvements, not a structural change. The briefs mostly changed because of the difference between the structure of the education programmes. For example, UL and UPC prepared the briefs based on the four-phase product development process. Including research, ideation, detailing and prototyping phases this programme structure correlated well with their teaching system and student profile. NHL and LiU, on the other hand, preferred to adapt the internship schedule to their programme structures. NHL used the multi-level design model for open innovation. According to this structure, the interns went through three phases of project development. These phases represent the three bottom levels in the multilevel design model including the socio-technical system, product-service system and product-technology system (Joore and Brezet, 2015). LiU adapted the internship schedule to its gate structure. LiU internship supervisors aligned the internship programme with the third-year studio course for the LiU students who attended the internship. They were supposed to take the third-year design studio course and continue with the

same project as their bachelor's degree thesis for the fourth year. Gate structure has four steps and some of the steps are similar to the four-phase product development (research, ideation, detailing, prototyping). Gate 1 is the feasibility study which can be compared to the research phase. Gate
2 is the planning state where interns identify the project's background, type, and character (goal-oriented or goal-seeking) to create different conditions for planning and execution. This step does not correspond to any phases of the four-phase product development. Gate 3 is the concept review which can be compared to the ideation phase of the collaborative action research process. Finally, Gate 4 refers to completion. Detailing and prototyping phases can be viewed together as completion steps and finalising the project.

Table 2. *The differences between the internship structures conforming to the four different education programmes.*

University partner	Internship duration	Programme structure	Scales of design	Assignments' field
UL	3 months 01.09.2017 – 28.10.2017	4 phase product development: 1. Research 2. Ideation 3. Detailing 4. Prototyping Masterclasses, workshops, field visits	Each project started with one of tl three scales of design 1. Materials 2. Products / Services 3. Whole systems	Reclaimed Material Exploration Retrofitting Food Waste Management
UPC	4 months 09.02.2018 – 20.06.2018	4 phase product development: 1. Research 2. Ideation 3. Detailing 4. Prototyping One month of lectures prior to the internship	Each project started with one of tl three scales of design 1. Materials 2. Products / Services 3. Whole systems	Material Innovation for Urban Application Selective Separation of Waste Municipal Waste Management
NHL	3 months 03.09.2018 - 23.11.2018	Triple helix of open innovation, level design model: 1. Socio-technical 2. Product-service 3. Product-technology Masterclasses, workshops, field visits	System perspective: each project focuses on all three scales of design 1. Product level 2. Strategy level 3. Service level	Rainwater harvesting and application Bioplastic Use and Sustainable User Experience Recycled Plastic Exploration

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LiU	3 months 04.02.2019 – 26.04.2019	Gate structure: 1. Feasibility study 2. Planning 3. Concept review 4. Completion Masterclasses, workshops, field visits	System perspective: each project focuses on all three scales of design 1. Materials 2. Products / services 3. Whole systems	Circular System for White Goods and Appliances Textile Circularity

The four internship programmes also used similar learning mediums. UL as the first internship programme utilised one-day masterclasses, workshops and field visits as structured learning mediums. Other than that, self-learning was facilitated through well-structured assignments. UPC started two months after UL's completion, according to the L4IDS project calendar. While the UL programme had a duration of 3 months, the UPC programme was conducted for 4 months because the UPC interns were offered the opportunity to share introductory courses with other local and exchange students. Therefore, UPC provided one-month lectures before the internship. The remaining two internships also utilised masterclasses, workshops and field visits as structured learning mediums like UL.

However, there were some application differences in the NHL's case. The previous two internships followed a structured schedule, with pre-determined lecture and workshop series whereas NHL preferred a more flexible one. NHL specializes in multidisciplinary courses where students from different departments come together to work on a design assignment. Most NHL students do not have a product design background, and circular design is a novel concept to them. Therefore, the initial strategy was to understand interns' level of knowledge and adapt certain parts of the schedule based on their needs throughout the project work. Apart from a certain number of courses that aimed at providing a holistic understanding of circularity, design process and prototyping, the internship followed a flexible structure where guest speakers were invited to work with the interns. This difference influenced how the briefs for the NHL internship were developed.

In order to diversify the kind of projects undertaken and maximise the potential of the internship, UL prepared each brief for one of the three levels of design. These three levels refer to materials, products/services, and whole systems. UPC also followed the same pattern. The project brief developed in collaboration with Zicla was focused on material exploration; the one with ENT was on the product/service level and the last one with UPC Recircula was on the whole system level. NHL followed a different path conforming to its education programme. They prepared the assignments on a product level, but also at a strategy level, and a service level. The product was not the ultimate focus of the process. The briefs were formulated in a way that the focus of the assignments shifted and narrowed down to the product level throughout the project. NHL also focused on the societal applicability of all three projects and challenged the interns to understand and explain the societal implications of their design. Finally, LiU prepared the project briefs based on the three scales of design like UL and UPC. However, they put the emphasis on realising all three levels in each assignment with a systems perspective.

6. Discussions and Conclusions

The internship programmes conducted as part of the L4IDS project aimed to convey the necessary skills and knowledge to novice designers and professionals while nurturing a future design practice inherently addressing the issues of sustainability. To achieve that purpose, the collaborating industry partners were carefully selected from sustainability-oriented companies or companies with a keen interest in adopting more sustainable practices, who are genuinely willing to make a transition towards a sustainable future.

Being in touch with the industry partners during the preparation phases has shown to be highly valuable for the development of a circular design brief. All four internships have prepared their briefs based on the previous internships' briefs and their extended schedule where they explain their suggestions. Based on the previous experiences, a draft version was created as the first iteration by the internship team. This draft was evaluated together with the industry partners through face-to-face meetings or phone calls in terms of their aspirations and goals for the internship. For example, UPC chose to send a questionnaire to the industry partners to understand their goals. The last step was to decide on the project deliverables and their dates and getting the approval of the project partners.

Through an iterative process, internship supervisors and industry partners have defined a series of tangible challenges that tackle real environmental problems. Although the interns were relatively free in terms of methodology and approach, the briefs provided a link to the Open Educational Resources database which includes a series of theories, tools, and methods related to the circular economy and sustainability. Naturally, in an international project with four academic partners, the internships had to be adjusted to the university cultures and institutional pedagogical preferences. It might not be possible to keep the same curriculum running in such a variety of academic contexts.

Based on the development process of eleven circular design project briefs, we have identified six characteristics of circular design briefs:

- From the start of the brief preparation process, the focus of the objectives of the circular design briefs was environmental problems.
- In the circular design briefs, circularity was considered as inevitable, not as an add on feature of products or services.
- The circular design briefs emphasised the importance of systems thinking in a circular economy.
- The circular design briefs emphasised the importance of collaboration in a circular economy.
- The circular design briefs tackled real-life challenges that participants found relevant and meaningful.
- Industry partners were selected from sustainability-oriented companies or companies that were willing to work on environmental challenges and develop circular design solutions.

In this study, the brief development process of eleven Circular Design Internship projects was examined. Based on the brief development process of these projects, five steps for brief making for circular design were presented. Some characteristics of circular design briefs were also identified such as focusing on environmental issues from the start and considering circularity as inevitable not an add on feature. Keeping the problem definitions broad was also another characteristic of these briefs which both eased the adaptability of the internship programme in different universities and enabled interns to produce a wide range of ideas. The results of this paper could be used

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by academics as a guide for preparing circular design briefs and by researchers who want to further explore the brief development process for circular design.

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Living Labs for research and education about Sustainable Housing, Technologies and Lifestyles at the ETSAV School of Architecture of UPC

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Abstract
Unsustainable resource consumption, GHG emissions and related climate change impacts are recognized results of our current model of consumption and production in so-called developed societies. In an increasingly complex world, with a constant growing amount of specialised knowledge, competence-based, real-world related learning is recognized as important method in higher education fostering e.g. in the fields of architecture and engineering the capacity of a holistic approach to these societal challenges, complementary to a traditional, disciplinary knowledge acquisition. Universities and especially schools of architecture, have an important role and a specific potential in this context. New forms of teaching and learning, fostering specific Sustainable Development (SD) related competences through experience-based and participatory learning processes with a holistic, pluridisciplinary view on sustainability, can strengthen their role in this transformation process. New approaches in the fields of research and innovation like open innovation processes and Living Lab ecosystems can overlap with these advanced SD related teaching and learning activities to mutual benefit from generated synergies. Living Labs e.g. can adopt the function of incubators for societal outreach regarding knowledge dissemination and the approach to societal challenges, generating projects and collaborations, which strengthen the role of university as an important change agent of society. Universities have a great opportunity to understand their own buildings and places as Living Labs or Campus Labs, facilitating these new approaches. UPC through its ETSAV School of Architecture uses since 2010 the Living Lab methodology based on its Solar Decathlon prototype Solar houses. Currently the fourth prototype is under construction and a corresponding post-competition use concept as Living Lab is under development. Living Lab LOW3, as the first of these Living Labs at UPC, is an educational research project under continuous development since 2011. During the last 8 years, a series of innovative teaching and learning activities has been implemented. Through qualitative and quantitative research methods the contribution of LOW3 to a holistic trans-disciplinary education in sustainability has been assessed. The experimentation of new teaching formats, methods and tools, the link between formal and non-formal learning, the exploration of personal learning environments of participants and the synergies between teaching, research and innovation have been focus of this educational research project. As a result, a comprehensive list of transdisciplinary fields of knowledge will be presented, highlighting the ones which have been explored in the context of the LOW3 Living Lab. This allows to exemplify the unique approach and the opportunities that offer prototype buildings for SD related research and teaching in higher education. www.livinglab-low3@blogspot.com

Keywords: Sustainable Lifestyle, Sustainable Housing, Living Labs, Prototype Solar Houses, Solar Decathlon

1. Introduction

HEIs have the important role for society of training future generations of professionals and leaders, generating the necessary knowledge, skills and competences for approaching current and future challenges related to sustainable development (SD). (Svanström et al. 2008)

Additionally, HEIs have the role of an agent for societal transformation, demonstrating how to overcome existing barriers to sustainability. By constantly searching for solutions from a collaborative, creative and open point of view based on diversity, a continuous search for further clarity and definition of the constant changing concept of sustainability allows avoiding its disciplinary simplification, and helps developing curricula based on sustainability concepts, including interdisciplinary, competence based, value and citizenship education as well as sustainability science principals (Sibbel 2009).

In order to implement SD holistically, HEIs need to start a transformation process, which includes not only curricula but also organizational and operational transformations. Institutional missions of HEIs must be redefined within a continuous critical review of knowledge and values (Wals et al. 2002) as our understanding of sustainability changes over time.

In the specific field of education for sustainability and ESD in architectural education, the co-creation of knowledge within a collective, problem-based or project-based learning process, eventually linked to experimental construction work, is considered highly effective in generating transformative learning experiences.

Education in the field of sustainability and specifically ESD requires also the definition of a whole set of new learning outcomes, which can be achieved best through specific learning environments, tools and methods, fostering ESD related knowledge, skills and competences and offering space for personal and collective definition of values.

This article states that Living Labs in Architecture, related to Higher Education Institutions (HEIs) might match particularly well this demand for new learning environments and methods, which offer specific qualities for ESD related teaching and learning activities. Architecture Living Labs, which often consist of student-built prototype houses, might contribute to discipline-based sustainability education as well as to holistic Education for Sustainable Development (ESD) in higher education, and with it, to the holistic transformation process of HEI's towards sustainable development. Important society-related fields of research and innovation which can be addressed in Architecture Living Labs are the sustainability of our built environment, housing solutions and lifestyles amongst many others.

In this sense Architecture Living Labs, besides being an efficient tool or methodology for crossing the "pre-commercial gap" of innovations (European Commission 2009), might be forerunners for a new and innovative way of sustainability related teaching and learning at universities, strongly linked to collaboration, co-creation and innovation in real-life contexts.

2. Methods

Theoretical research on Living Labs as well as ESD has been done, as well as field research methods have been applied in order to evaluate Architecture Living Lab initiatives at UPC. Research is divided into the following fields:

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- Analysis of the concept of Living Labs and the corresponding theoretical framework, introducing the specific concept of Living Labs in Architecture and describing a framework of Living Labs in HE.
- Proposal of a framework for Architecture Living Labs in HE with focus on education for sustainable development (ESD) in the field of sustainable architecture and a more sustainable life style.
- Description and analysis of the *Living Lab* LOW3 project as specific case study of an Architecture Living Lab focused on ESD at UPC. This case study can be defined as an educational action research project under the leadership of the author, in continuous development since its start in 2011.

Aim is to contribute to a better understanding of the role which Architecture Living Labs can have, for the necessary shift towards a participative educational model, which brings together theory and practice, teaching, research and innovation, as well as societal outreach activities in one place in order to foster HEI's role in the holistic societal transition towards SD.

3. Living Labs in Architecture

According to European Network of Living Labs (ENoLL), "*a Living Lab is a real-life test and experimentation environment where users and producers co-create innovations",* with four main activities typically employed by Living Labs:

- **Co-Creation**: co-design by users and producers
- **Exploration**: discovering emerging usages, behaviors and market opportunities
- **Experimentation**: implementing live scenarios within communities of users
- **Evaluation**: assessment of concepts, products and services according to socio-ergonomic, socio-cognitive and socio-economic criteria.

On the other hand, the main constituting characteristics of Living Labs have been identified as the following:

- **Multi stakeholder approach**: often based on a PPP (Public-Private-Partnership)
- **User involvement**: giving a special role to the user as part of the innovation process
- **Open Innovation**: considering innovation as an open process with multiple stakeholders
- **Real-life environment**: experimenting and capturing user insights in real-life contexts

Understanding these 4 principal activities and these 4 constituting characteristics as a framework for the definition, operation and management of Living Labs, a closer look can be made on Living Labs in Higher Education Environments with a specific focus on Architecture Living Labs and focused on ESD, describing synergies and identifying possible common strategies and concepts of Living Labs and ESD.

Living Labs in Higher Education Environments

A general typological framework for Living Labs regarding their places and functions within HE is represented graphically in Fig. 1. Considering that the traditional fields of activity in Higher Education Institutions are divided into Teaching, Research and Innovation and Outreach, Education for Sustainable Development activities are located in the field of Teaching as a supplement to traditional disciplinary educational practices (or somehow integrated and merged with them, which is an on-going discussion), and are also linked to the fields of Research and Innovation and Outreach.

Living Labs appear at the cross-section of all areas, giving place to research focused, innovation and outreach focused, and education focused Living Labs, or located at the center point of all three areas, to ESD focused Living Labs.

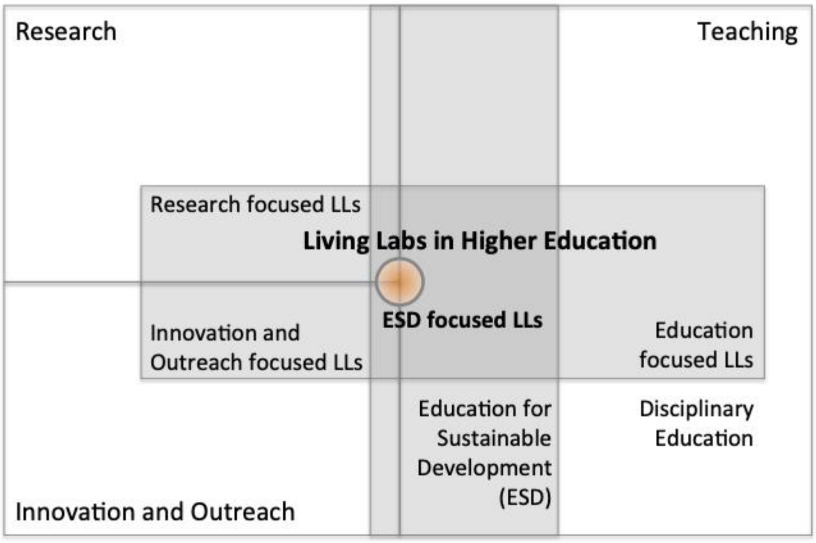

Figure 1: Framework of Living Labs in Higher Education – HE Living Lab Ecosystem (Masseck 2016)

All these forms of HE Living Labs generally have a set of stakeholders behind them, consisting of industry, administration or society-based partners, constituting different forms of Public Private (PPP) or even Public Private People Partnerships (PPPP).

This opens up diverse Living Lab initiatives in HE towards society and allows for example, integrating the ESD component of academic Living Labs into life-long-learning activities in its societal context, creating synergies and building up a Higher Education Living Lab Ecosystem with a strong outreach to society.

Nevertheless, a continuous transition between teaching, research and innovation and outreach activities can be assumed for most Living Labs, and many initiatives have a strong link to all three areas, with SD and ESD as common paradigms. Overcoming these traditional, sectorial limits of academic activities allows to understand Living Labs in HE as Holistic SD Transition Arenas, where creative group processes allow developing innovative ideas and concepts (Loorbach & Rotmans 2010).

4. Framework of Living Labs for ESD within HEIs

Main drivers of Living Labs in their generic definition are mainly companies which are interested in accelerating a specific product or service development in order to get to the market after testing as quick as possible, optimizing the product or service in a real-life setting with real users. (Almirall & Wareham 2008)

Within an academic Living Lab, e.g. in the field of architecture, with university as main driver, knowledge generation and experience-based learning through testing and implementation of new solutions with users under real conditions of use might prevail over the pure objective of market-readiness of a product or service. The campus as experimental field for prototyping serves generally both: teaching and research on one hand, innovation and industry collaborations for product and service development on the other hand.

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A second purpose can be the knowledge generation and prototype application for the improvement of HEIs campus buildings, infrastructures, services and operation i.e. regarding energy efficiency, environmental sustainability and SD in general, contributing to a HEIs' transition to SD as an organization, community and societal stakeholder. As an open collaborative platform, they can serve as places for bottom-up initiatives regarding a holistic transition process of HEI's towards SD. As a result of these campus specific Living Lab dynamics, teaching, research, experimentation and innovation merge together in order to offer a holistic, transformational learning experience to all stakeholders, students, researchers, teachers and employees of a campus.

A third mission of Higher Education Institutions is to generate outreach to society, with a positive impact on the social and economic context of university, contributing to solve societal challenges and disseminate the generated knowledge to society. Outcomes of academic Living Labs might therefore be generally prototype solutions instead of market-ready products or services. Living Labs might serve as transversal innovation platforms for the academic community of HEIs, with other entities like innovation units, incubators and spin off promotion offices smoothly supporting the further development of ideas and concepts towards the market.

Fig.2 represents the 3 basic fields of activity of HEIs as societal actor regarding SD, with the possibility for Living Labs fulfilling specific internal and external functions and adopting the role as connecting elements between HEIs and society in all 3 areas:

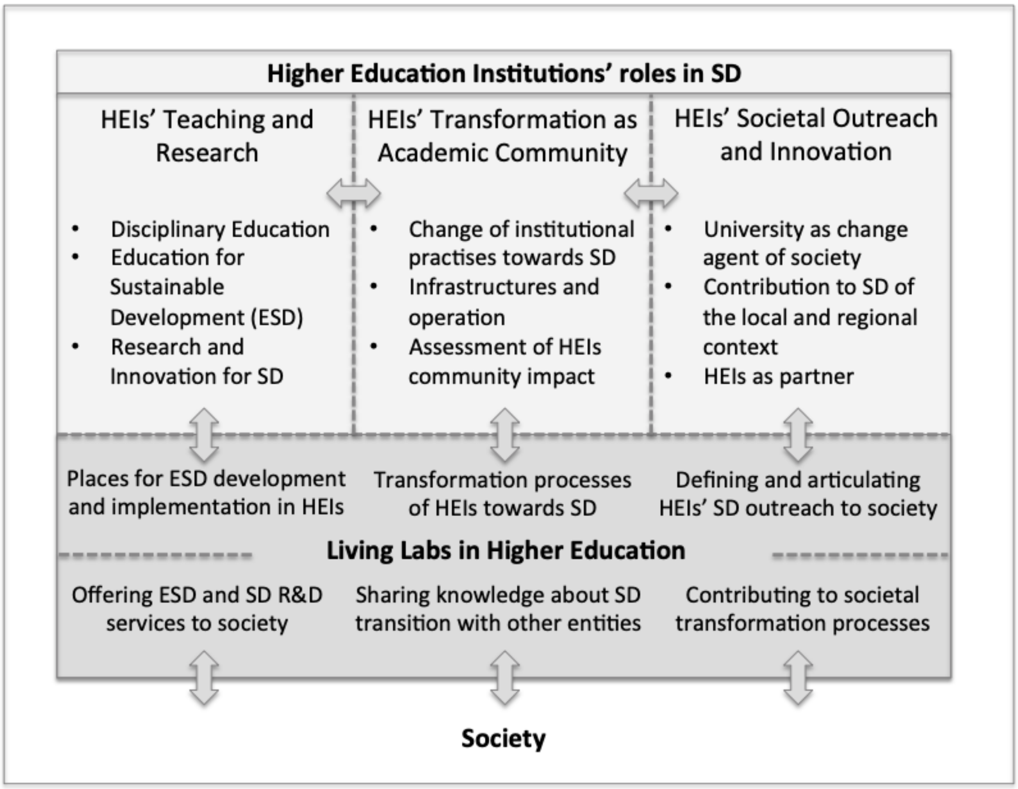

Figure 2: *Living Labs as connecting elements regarding SD between HEIs and society (Masseck 2016)*

Specifically, Living Labs can have the following role and functions:

HEIs' Teaching, Research and Innovation:

Living Labs can *internally* develop and implement ESD and related teaching and learning strategies, methods and tools in order to promote the integration of SD knowledge, skills and competences in teaching, research and innovation, offering *externally* ESD and SD related R&D services to society.

HEIs' institutional transformation towards SD:

Living Labs can *internally* foster transformation processes towards SD of HEIs as communities with their institutional practices, infrastructures and assessment tools and share *externally* the generated knowledge about SD transition with other entities.

HEIs' societal outreach:

Living Labs can *internally* be places to define and articulate HEIs' outreach to society in order to structure the role of universities as change agents, contributing *externally* to societal processes of transformation towards SD within their local and regional context.

5. Living Labs and ESD key strategies

Regarding key strategies which connect Living Lab activities to ESD, Problem based learning and Project based learning (PBL) and lately Challenge Driven Education (CDE) are three outstanding educational methods, which can be directly related to Living Lab activities due to their applicability for tackling complex technological, societal or environmental problems and challenges in a holistic, cooperative and creative way.

Also other ESD related educational concepts, methods and strategies are in line with Living Lab activities, e.g. Role play, Scenario building, Qualitative and quantitative modeling, Participatory modeling, Dealing with uncertainty, Multi-criteria assessment, Envisioning methods, Life-cycle assessment, Risk analysis, Negotiation and Value discussion (from Wiek et al. 2011). In the following 3 key strategies of ESD are shortly defined and their possible synergies with Living Lab environments and methodologies are described:

Key strategy 1: Problem based Learning

Problem based learning stimulates a participatory process of knowledge generation, value discussion and solution finding for a specific presented problem. It's a cooperative and active approach to learning

According to Segalàs (2009) the constructivist theory relates to problem-based learning in three aspects, which in the following will be correlated to basic principles of the Living Lab approach:

- *The understanding of a situation of the reality appears from the interactions with the surroundings:* Real-life environments and context relation of Living Labs facilitate this interaction in multiples ways.
- *The cognitive conflict in facing each new situation stimulates learning:* Living Labs are Experimental Learning Environments, which generate constantly new situations and therefor stimulate learning.
- *The knowledge develops through the recognition and acceptance of social processes and of the evaluation of the different individual interpretations of the same phenomenon:* Living Labs are based on multi stakeholder processes and pluridisciplinary co-creation activities, which constantly confront participants with societal realities and different interpretations.

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(Segalàs 2009, p. 41)

Due to the described similarities, innovation processes in Living Labs could be designed as Problem based Learning activities in Higher Education, integrating students of a discipline in specific co-creation projects with students from other disciplines (closed academic Living Lab exercise) or with other stakeholders like companies, public administrations, citizens (open academic-societal Living Lab process).

Key strategy 2: Project Based Learning (PBL)

Project Based Learning is a holistic learning method, which encourages students to apply their knowledge, skills and competences in order to cooperatively design and implement a real project. Corresponding learning environments should be open and context related, inspiring and equipped for dynamic group work and discussions. Basic principles are amongst others:

- Co-creation of a project in an open and creative environment, including value discussions
- Pluridisciplinary approach in order to solve complex challenges
- Projects refer to real-life problems in their specific context

Considering the complexity of sustainability challenges, and the need for a wide, context related scope of projects, the project based learning approach efficiently fosters the collaboration in interdisciplinary teams on complex societal themes and in an integral and creative way (Mulder cited in Segalàs 2009, p. 38).

Principles of PBL match fairly well with Living Lab principles and due to similarities in methods and approach, Living Labs could be the inspiring environments hosting related activities.

Key strategy 3: Challenge Driven Education (CDE)

Challenge Driven Education (CDE) is an even more holistic learning method than Problem or Project based learning and encourages students to understand specific, complex challenges of society in order to define not only possible solutions, but the right questions to be made, in order to identify the real conflict or challenge and to develop holistic strategies as well as specific solutions which might contribute to an overall improvement.

Basic principles are amongst others:

- Co-creation of a solutions to society embedded, relevant challenges, defined by societal stakeholders
- Development of a deeper knowledge of challenge related aspects through the real-world context
- Students take action and develop or even implement solutions

Considering the complexity of challenges, and their specific, society embedded scope, including the development and implementation of solutions, CDE might exceed the possibilities of Living Labs although Living Labs could be the inspiring environments hosting CDE related activities.

6. The UPC Living Lab ecosystem

UPC through its ETSAV School of Architecture uses since 2010 the Living Lab methodology based on its Solar Decathlon prototype Solar houses. Currently the fourth prototype is under construction and a corresponding post-competition use concept as Living Lab is under development.

Altogether, the three existing Living Lab – prototype buildings can be considered as a *Living Lab Ecosystem* (Fig. 3) which has enriched deeply the educational practice at ETSAV, including prototype planning and construction into curricula and converting the ETSAV campus regularly in an experimental building site.

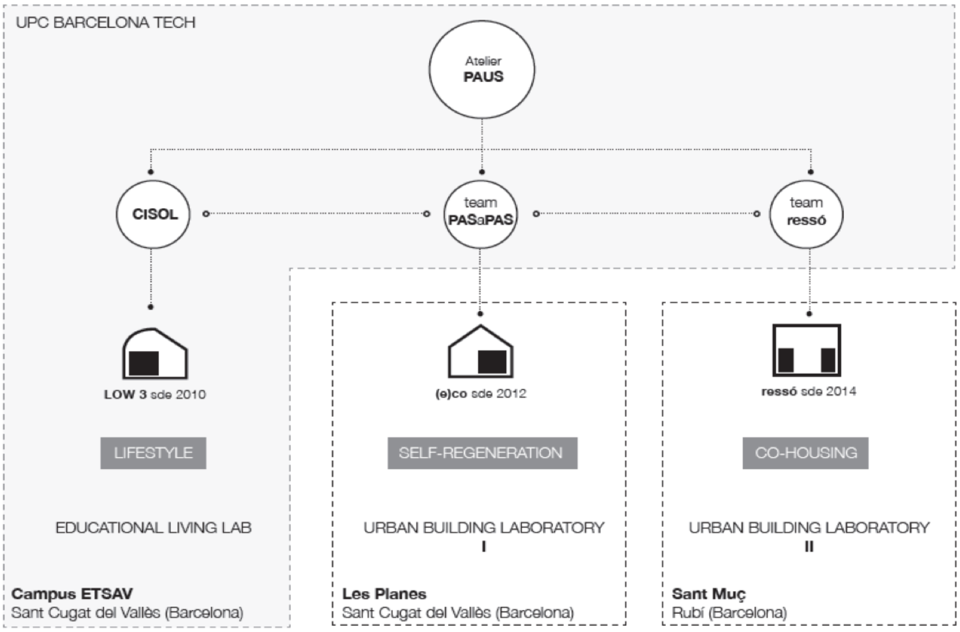

Figure 3. *Living Lab Ecosystem ETSAV (UPC)*

Each prototype solar house (Fig. 4) has been developed and implemented as a Living Lab for its post-competition use. The LOW3 prototype (SDE 2010) has been implemented as Educational Living Lab at the ETSAV campus in Sant Cugat and since 2011 serves as a platform for educational innovation projects, as well as research and innovation activities.

Figure 4. *UPC Living Labs LOW3,(e)co and RESSÒ*

The (e)co prototype (SDE 2012) has been reconstructed by its student team in the close-to-university neighbourhood of Les Planes and since 2013 operates as an Urban Living Laboratory for reactivating a residential area with a lack of infrastructure and services due to a difficult geographical location and specific population structure, with a high unemployment rate and problems related to energy poverty.

The RESSÒ prototype (SDE 2014) has been reconstructed in 2014 in Rubí (Barcelona) with support of the local administration, specifically in the low-density neighbourhood of Sant Muç. Since then it houses initiatives and activities focused on the social cohesion and energy refurbishment of housing of the neighbourhood. It is meant as a polyvalent space, which could contribute palliate energy poverty problems of society and give service to the community in general.

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All three projects are used or operated by their original student teams and have generated an impressive amount of activities and outreach to society, fostering universities role as change agent.

Living Lab LOW3

Living Lab LOW3, the first Living Lab at ETSAV (UPC), is based on the LOW3 prototype solar house which was built by a student team under the lead of the author for the Solar Decathlon Europe competition 2010. It can be considered an educational research and innovation project under continuous development since 2011.

During the last 8 years, a series of innovative teaching and learning activities has been implemented. Through qualitative and quantitative research methods the contribution of LOW3 to a holistic trans-disciplinary education in sustainability has been assessed. The experimentation of new teaching formats, methods and tools, the link between formal and non-formal learning, the exploration of personal learning environments of participants and the synergies between teaching, research and innovation have been focus of this educational research project.

The concept of Living Lab LOW3 is that of an activity's platform with a participatory approach to teaching and learning based on a prototype solar house, offering its spaces, its equipment and its infrastructure to diverse user groups from both inside and outside the UPC. Teaching and learning activities take place online and in-person in parallel with research projects and outreach activities in order to create synergies between sectors, people and disciplines. Finally, Living Lab LOW3 is also a place for the networking of people in order to engage in new sustainability projects and initiatives, fostering the human factor behind these activities (Fig 5).

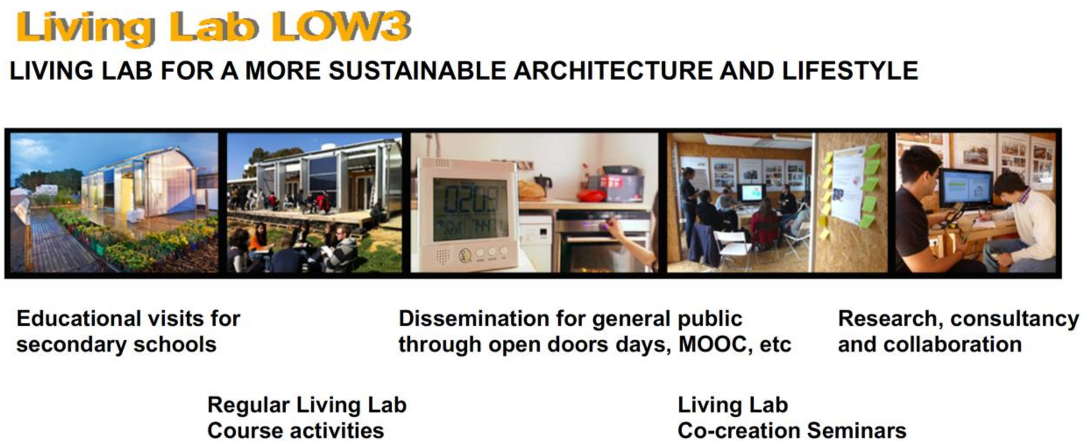

***Figure 5**. LOW3 Living Lab activities.*

One of the most intense, experience-based, transformative teaching and learning activities has been the 'Live-at-LOW3' experiment, a house occupation experiment in 2012. The 'Live-at-LOW3' experiment was carried out within the elective course "Living Lab LOW3", linked to the Master Program Sustainability (IS.UPC) and the ETSAV undergraduate program.

The house-occupation experiment has been a holistic approach to user-centred research. Two selected students evaluated and tested the prototype solar house during 14 days with the participating course students preparing, accompanying and evaluating the experiment through the monitoring and evaluation of the inhabitant's lifestyle with a holistic view on housing, consumption, food and mobility. This course had a transformative effect on its participants, as in parallel to the generated theoretical knowledge about sustainable lifestyles, the related experience-based learning showed to be highly effective.

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The experiment included the following experiential activities:

- Monitoring energy consumption (daily consumption, relation to daily activities, comparison with solar energy production)
- Assessing water consumption (grey water recycling, dry toilet, water saving measures)
- Measuring waste production (daily production, type and weight)
- Assessing indoor comfort (day and night comfort in the house, privacy, air quality, noise)
- Reporting about food habits (local market, own vegetable garden and even 2 hens at the campus)
- Calculating the overall ecological footprint of the inhabitants

Results were published in course reports, the experiment was filmed and published through a documentary as well as local newspapers, and television showed interest in the experiment and its outcomes. A holistic learning and user-centred research process was conducted in order to evaluate the LOW3 solar house, its concept, its technologies, and the resulting comfort for inhabitants.

A wider engagement of the academic community, as well as society in general, could be achieved through open door days, media interest (national and local TV and radio emissions, digital newspapers) and the use of social networks and ICT (YouTube channel for video diary, documentary, live webcam).

The educational experiment was very successful, with students evaluating their participation and related learning as very positive. Nevertheless, the educational format had to overcome administrative and legal issues, was time consuming for all participants, depending on a special personal commitment of all participants, and needed a certain amount of economic resources, which are the reasons why this format could not be repeated since then.

7. Results and Discussion

ESD in higher education forms part of a complex transformation process of the whole higher education systems today. Whereas ESD is mainly focused on new approaches to teaching and learning, sustainability science can be considered the corresponding paradigm in the fields of research and innovation. On the other side it is important to state that HEIs' institutional transformation (governance, infrastructures, operation, academic community) and HEIs' outreach to society regarding SD are important complementing elements for a holistic approach to education for sustainable development from a HEIs' point of view.

It shows that Living Labs can play a major role in articulating all three fields of activity of HEIs towards society, offering a physical and methodological framework for interaction. Living Labs e.g. can adopt the function of incubators for societal outreach regarding knowledge dissemination and the approach to societal challenges, generating projects and collaborations, which strengthen the role of university as an important change agent of society.

The UPC Living Lab ecosystem, consisting in 3 different prototype buildings, built by student teams and operated in cooperation with stakeholders from local governments and administration, shows how this theoretical framework can be implemented, creating considerable impact in both, university and society.

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Results Living Lab LOW3

The specific impact of the LOW3 Living Lab can be quantified through the amount of initiatives carried out and the involvement and participation of students and visitors with the following results after 8 years of operation:

- 8 regular Living Lab LOW3 courses
- 8 Innovation and co-creation seminars on Master level (InnoEnergy)
- 2 International Summer Schools
- 1 House occupation experiment ”Live-at-LOW3”
- 5 open doors days
- 30 educational visits in collaboration with different schools and HE programs
- More than 40 specific events which took place at LOW3
- Overall student participants: 500
- Overall visitors: 2000

Nevertheless, many of the outcomes of this initiative cannot be assessed or quantified easily, as they refer to the creation of networks and collaborations and educational outcomes in a non-formal learning environment, e.g. in the field of value discussion and interpersonal competences.

Critical aspects of Living Labs in HE

Living Labs are complex projects with a huge variety of stakeholders to coordinate and several challenges to solve regarding infrastructure, financing, management and related issues. Based on the experience of 8 years of operation of the LOW3 prototype as a Living Lab at the ETSAV School of Architecture, the following critical aspects of Living Labs in HE can be mentioned:

- **Lack of institutional integration:** Lack of institutional support and clear research/teaching frameworks which allow integrating Living Labs and their dynamics in universities, their existing curricula and operational structures.
- **Missing culture of collaboration:** Missing aspects of collaboration between university-company-administration in the field of open innovation through Living Labs and the use of real-life environments.
- **Complexity of the Living Lab approach**: Complexity of Living Lab approach due to the number of stakeholders involved, its pluridisciplinarity and the physical infrastructure related to it.
- **Recent appearance:** Due to the relatively recent appearance of living lab activities in higher education there is only limited experience and a lack of evaluated operational and business models.

These aspects have to be addressed by HEIs in order to facilitate support and solutions to current and future Living Lab projects.

8. Conclusions

ESD education for architects and related disciplines benefit deeply from the concept of Living Labs in architecture as this type of project allows the application of specific teaching and learning methodologies, which foster ESD skills and abilities and competences.

A general framework for Living Labs in HE and a corresponding HE Living Lab Ecosystem have been described in order to understand the variety of Living Lab typologies related to HE environments and to define the position of ESD focused Living Labs within this ecosystem. Living Labs have been described as *Holistic SD Transition Arena*, a place where HE traditional disciplinary and new sustainable paradigms merge and activities increasingly focus on a combined teaching, research, as well as innovation and outreach approach.

ESD related competences and strategies have been associated with the 4 main characteristic of the Living Lab approach: the multi stakeholder approach, the user involvement approach, the open innovation approach and the real-life setting approach, stating that Living Labs can be valuable concepts for ESD and even serve as transformational tools for HEI's transition towards SD.

Field studies of Living Lab projects at UPC show the diversity of approaches and their potential to create a Living Lab Ecosystem, but also allow identifying a series of strengths and weaknesses of the concept regarding organization and management, integration into the established academic settings or sustainability of projects over time, which need to be addressed and overcome in order to integrate more widely Living Labs as educational tools in HE.

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Resource efficiency

Recycling Bulk Chemicals

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Abstract

The world's population growth, climate change and increasing demand for energy and resources are the drivers behind the need to find recycling solutions, also in the production of bulk chemicals. In addition, increasing urbanization, especially in Asia and Africa, causes waste management problems, resulting for example in the accumulation of plastics not only on land but also in the oceans. Chemicals are the cornerstones of modern life, and plastics are one of the chemicals produced in bulk quantities. The volume of plastic waste in the oceans is increasing at a rate of about eight million metric tons every year. This illustrates the magnitude of the chemicals recycling problem in waste management that awaits a solution. Collection of plastic waste prior to landfilling and preventing the leakage of already landfilled plastic waste would considerably reduce the volume of plastics entering the oceans. The chemical sector is the largest industrial energy consumer and responsible for approximately seven percent of anthropogenic global greenhouse gas emissions, and five and half percent of carbon dioxide emissions alone. This makes the chemical sector the third largest industrial emitter of carbon dioxide after steel and cement production. Recycling and production of renewable chemicals offer opportunities to reduce greenhouse gas emissions and to close the carbon loop. This study focuses on the possibilities to recycle or reuse/regenerate key bulk chemicals from waste streams or non-conventional resources, with special emphasis on managing greenhouse gas emissions. The methodology used is a three-tier process comprising a statistical survey and a consequent rating for the selection of chemicals to be included in the study, followed by the evaluation of technological choices, both upstream and downstream in the supply chain. Finally, the study is completed with a robust life cycle analysis, including greenhouse gas emissions, to evaluate bulk chemicals and technological choices identified as the most promising. Focusing on improved technological processes for ammonia, methanol, ethylene, propylene, polyethylene, polypropylene, polyethylene terephthalate and polyvinylchloride has the potential to reduce global greenhouse gas emissions by 876 Mt CO_2eq yr^{-1}, provided that all of the current global production is upgraded to the level of the European Union's benchmarked facilities. These upstream improvements in resource efficiency would mean a 25% reduction of all global chemical sector emissions. However, the probability for all global production facilities to reach the EU benchmarked values is unclear. Even an incremental 10% improvement in the efficiency of upstream supply chains would reduce greenhouse gas emissions by 88 Mt CO_2eq yr^{-1}. On the downstream side, increasing the recycling rate of non-fibrous plastic resins from the current 18% to 42% would reduce global greenhouse gas emissions by 142.3 Mt CO_2eq yr^{-1}, provided that incineration is not increased, and that the segregation of recyclable materials is improved. These downstream improvements in recycling would mean an additional 4% reduction of all global chemical sector emissions.

Keywords: Bulk Chemicals, Circular Economy, Recycling, Climate Change, Greenhouse Gases

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1. Introduction

The world's population growth, climate change and increasing demand for energy and resources are the drivers behind the need to find recycling solutions, also in the production of bulk chemicals. In addition, increasing urbanization, especially in Asia and Africa, causes waste management problems, resulting for example in the accumulation of plastics not only on land but also in the oceans. Chemicals are the cornerstones of modern life, and plastics are chemicals produced in bulk quantities. The vast majority of monomers used to make plastics, such as ethylene and propylene, originate from fossil hydrocarbons. None of the commonly used plastics are biodegradable. As a result, they accumulate, rather than decompose, in landfills or in the natural environment. The volume of plastic waste in the oceans increases at the rate of about eight million metric tons every year (Eriksen et al., 2014; Jambeck et al., 2015). This illustrates the magnitude of the chemicals recycling problem in waste management awaiting a solution. Collection of plastic waste prior to landfilling and preventing the leakage of already landfilled plastic waste would considerable reduce the volume of plastics entering the oceans. Several countries are also restricting the use of disposable single-use plastic utensils. Canada recently announced a ban on the use of these utensils in 2021 following the example of the European Union. The importance of this decision is significant. Currently Canada recycles only 10% of plastics consumed in the country (WWF, 2019). Another large bulk chemical sector, fertilizers, causes leakage to waterways and increases considerably the accumulation of phosphorus and nitrogen in seas and lakes causing uncontrolled algae growth and other hypertrophication problems.

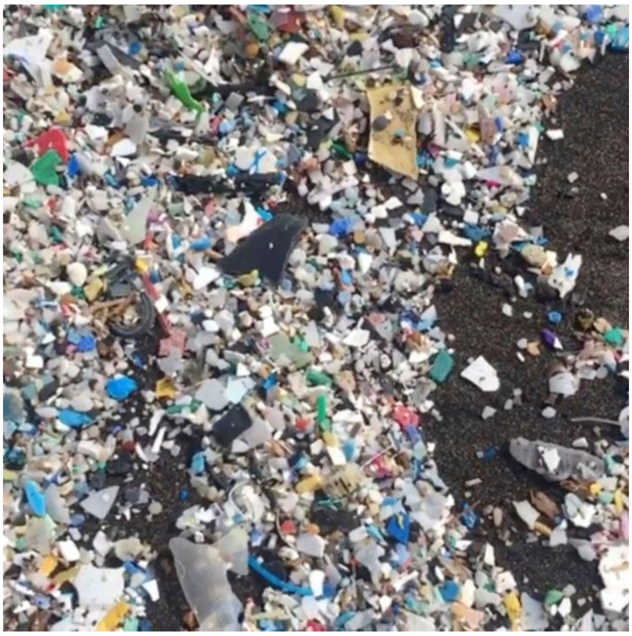

***Figure 1**. Plastic waste on the beach of Argaluzan Playa Grande in Puerto del Carmen, Tenerife. Photo taken on 24 March 2019 by Maria Celma, Argaluza/Oceano Limpio Tenerife via REUTERS.*

The chemical sector, the producer of bulk chemicals, is the largest industrial energy consumer and responsible for approximately seven percent of anthropogenic global greenhouse gas emissions, and five and half percent of carbon dioxide emissions alone (IEA et al., 2013). This makes the chemical sector the third largest industrial emitter of carbon dioxide after steel and cement production (IEA, 2017). Much effort is being directed to reduce the energy use of the sector, and to improve the efficiency of chemicals production. However, less attention is being paid to the recycling of key bulk chemicals.

The global accumulation of plastics is ubiquitous throughout our ecosystem including the marine environment. Recently, this issue has rocketed into public attention and increased scientific interest in the problem. The World Bank and the World Wildlife Fund (WWF) have both recently published reports on plastic waste management including future projections up to 2030 and 2050 (WWF, 2019; Kaza et al., 2018). Eriksen et al. (2014) estimated the total number and weight of the plastic particles floating in the world's oceans from 24 expeditions between 2007 and 2013 using surface net tows and visual survey transects of large plastic debris. The results obtained with an oceanographic model of floating debris dispersal included correction for wind-driven vertical mixing. The estimates resulted a minimum of 5.25 trillion particles weighing 268,940 metric tons. The quantity of plastic entering the ocean from waste generated on land was estimated at 4.8 to 12.7 million metric tons (Mt), based on 2010 data of 275 Mt of plastic waste generated in 192 coastal countries (Jambeck et al., 2015). The mapping of plastics produced, used, and the fate of all plastics ever made, was estimated by Geyer et al. (2017). This first global analysis of all mass-produced plastics ever manufactured concluded that 8300 Mt of virgin plastics had been produced by 2015, and approximately 6300 Mt of plastic waste generated. The recycling rate had reached 9%, 12% had been incinerated, and 79% had accumulated in landfills or in the natural environment. This mapping concluded that, if current trends continued, approximately 12,000 Mt of plastic waste would be in landfills or in the natural environment by 2050. The study proposed that the only way to eliminate plastic waste would be by destructive thermal treatment, such as combustion or pyrolysis. In addition, concerns regarding human consumption of microplastics are growing, although the effects on human health are largely unknown and the exposure risks are unresolved (Cox et al., 2019). The increasing accumulation of plastics in ecosystems needs attention and innovations since a total ban on plastics is hardly an option to solve the problem.

Levi and Cullen (2018) mapped the global chemical sector mass flows for key bulk chemicals based entirely on public data available in 2013. They extrapolated mass flow units to millions of metric tons per year (Mt yr^{-1}) of production, excluded internal recycle loops, treated production facilities as 'black box' processes, and assumed that the majority of chemicals are stored and transported between supply chain elements in less than one year. Production figures often derived from reported or assumed utilization ratios of plant capacities. Their work also gives an indication of the carbon dioxide emissions of the sector. They stress that the robustness of data and lack of statistics increased the uncertainty of their results. The production of plastics and nitrogen fertilizers was estimated at 329.4 Mt and 274.7 Mt respectively in 2013.

Caps in global production and materials flow data of key bulk chemicals exist. However, for plastics, the identified research gaps are manifold; the relative advantages and disadvantages of dematerialization, substitution, reuse, material recycling, waste-to-energy and conversion technologies need careful assessment (Geyer et al., 2017). We need less littering, more recycling, and new routes for recovering and utilizing plastic waste as a raw material.

Recycling and production of renewable chemicals offer possibilities to reduce greenhouse gas emissions and to close the carbon loop. This study focuses on the possibilities of combining the management of greenhouse gas emissions and recycling or reproducing key bulk chemicals from waste streams or non-conventional resources with special emphasis on win-win solutions. The methods are explained in section 2 followed by results and

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discussion in section 3. The conclusions are given in section 4.

2. Methods

The aim of this study is to identify the possibilities of combining the management of greenhouse gas emissions with resource efficiency, recycling or reproducing key bulk chemicals from waste streams or non-conventional resources. The methodology used is a three-tier process comprising of a statistical survey and a consequent rating of the chemicals to be included in the study, followed by the evaluation of technological choices, both upstream and downstream of the supply chain. Finally, the study is completed with a robust life cycle analysis, including greenhouse gas emissions, for assessing the bulk chemicals and technological choices identified as the most promising.

2.1. Statistical survey

The aim of the statistical survey is to find the key chemicals suitable for recycling among the numerous commodity chemicals produced. The priority is bulk chemicals originating from a fossil resource base. The survey includes data collection, analysis and assumptions.

Data collection

The production statistics of key bulk chemicals were compiled from existing public sources. Attention was especially placed on chemicals from fossil resources that accumulate in landfills or litter the environment and leak to seas and lakes. Inorganic bulk chemicals, like phosphoric and sulphuric acids and N fertilizers, were excluded from the survey. Plastic production, waste generation, recycling and incineration data rely on Geyer et al. (2017), and on the numerous data resources used in their analysis.

Data analysis

The scoring of chemicals based on annual production volume, waste generation, recycling and incineration rate reveals the chemicals beneficial for recycling from waste streams or for regeneration/reuse from waste or renewable resources. The weighting of the scoring is as follows:

$$Total\ Score\ (i) = \sum Prod\ (i) + Waste\ (i) - Recycle\ (i) - Incinerate\ (i) \qquad Eq.\ 1,$$

where *i* is the chemical, *Prod* is the amount produced in Mt yr^{-1}, *Waste* is waste generation in Mt yr^{-1}, *Recycle* is the amount recycled in Mt yr^{-1} and *Incinerate* is the amount incinerated in Mt yr^{-1}. According to the results of the scoring, the chemicals are rated, and those with the highest scores are selected for further evaluation.

Data assumptions

Sensitivity analysis with regard to plastic waste generation and recycling data is from Geyer et al. (2017), with an average standard deviation between -4 and + 5%. Similarly, the assumption is that end-of life textiles with synthetic fibres are incinerated or discarded together with all other municipal solid waste. Assumptions for the recycling and incineration rates of chemicals are given in section 3.1. Assumptions used in the life cycle analysis are given in section 3.3.

2.2. Evaluation of technological choices

The production routes of selected chemicals were analysed. Different production routes for each chemical were assessed using the volumes of production and waste generation from Eq.1 as a base. The supply chain analysis of each chemical includes both upstream and downstream options. These include assessment of substitution, reuse, material recycling, waste-to-energy and conversion technologies. In particular, the focus is on the possibilities of increasing direct recycling, changing to renewable resources and improving resource efficiency. When relevant,

the upstream supply chain analysis of Levi and Cullen (2018) was applied. The downstream options for plastics rely on the consumption profiles identified by Geyer et al. (2017) and WWF (2019).

2.3 Life cycle analysis

Life cycle assessment (LCA) is a common standardized tool (ISO 2006a, ISO 2006b). We used attributional life cycle assessment (ALCA) to assess the amount of greenhouse gases (GHG) expressed in carbon dioxide equivalents (CO2eq). The approach is on a cradle-to-gate basis for upstream options. The boundary conditions for downstream options were defined case by case. Every use of allocation, either energy or economic, is included. The functional unit considered is one metric ton of chemical produced or recycled. The assessment is limited to the impact category of GHG emissions. The life cycle inventory (LCI) data is based on references. Fully-fledged, detailed LCAs for each chemical are beyond the scope of this study. The robustness and sensitivity of the obtained results are addressed, and the limitations of the method used are discussed.

3. Results and Discussion

The results start with the identification and rating of the key bulk chemicals on a global scale. Thereafter follows the analysis of the production routes of selected chemicals. The results cover the evaluation of different technological options, both upstream and downstream of the supply chain, taking into account the specific consumption patterns of each chemical. Finally, the study is completed with a robust life cycle estimate of the greenhouse gas emissions of the potentially best options for reducing virgin material consumption and greenhouse gas emissions in the production chain of each chemical.

3.1. Statistical survey

The analysis of available production data revealed 13 bulk chemicals as the most prevalent for further screening with potential for recycling and reuse/regeneration from waste or renewable resources. In order of magnitude, these chemicals are as follows: ethylene (C_2H_4), ammonia (NH_3), urea, methanol (CH_3OH), propylene (C_3H_6), high-density polyethylene (HDPE) and low-density and linear low-density polyethylene (LD&LLDPE), polypropylene (PP), polyester, polyamide and acrylic (PP&A) fibres, polyvinylchloride (PVC), polyethylene terephthalate (PET), polyurethane (PUR) resin and polystyrene (PS). The production data for these chemicals is shown in Table 1. The global production of plastic resins and fibres including their additives reached over 400 Mt in 2015. On average, non-fibrous plastics contain 93% polymer resin and 7% additives by mass. In addition to the plastic resins and fibres listed in Table 1, the production of other polymers and additives accounted for 41 Mt (Geyer et al. 2017). Bio-based or biodegradable plastics currently have a global production capacity of only 2.1 Mt and are excluded from these statistics (European Bioplastics, 2017). NH_3, urea, C_2H_4, CH_3OH and C_3H_6 are intermediates for the production of both plastic resins and fibres, and are commodity chemicals widely utilized for various applications.

Table 1. *Production of key bulk chemicals in Mt.*

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Chemical	Production in Mt	Ye	Reference
Ammonia	175	20	USGS (2017)
Methanol	95	20	Räuchle et al. (2016)
Urea	173	20	IHS (2016b)
Ethylene	177	20	IHS (2017)
Propylene	96	20	IHS (2016a)
HDPE	52	20	Geyer et al. (2017)
LD&LLDPE	64	20	Geyer et al. (2017)
PP	68	20	Geyer et al. (2017)
PS	25	20	Geyer et al. (2017)
PVC	38	20	Geyer et al. (2017)
PET	33	20	Geyer et al. (2017)
PUR resins	27	20	Geyer et al. (2017)
PP&A fibres	59	20	Geyer et al. (2017)

The geographical distribution of the consumption of ethylene (Figure 1) and propylene (Figure 2) is adapted from IHS (2017) and IHS (2016a). These consumption figures also give an indication of the geographical distributioof plastics production.

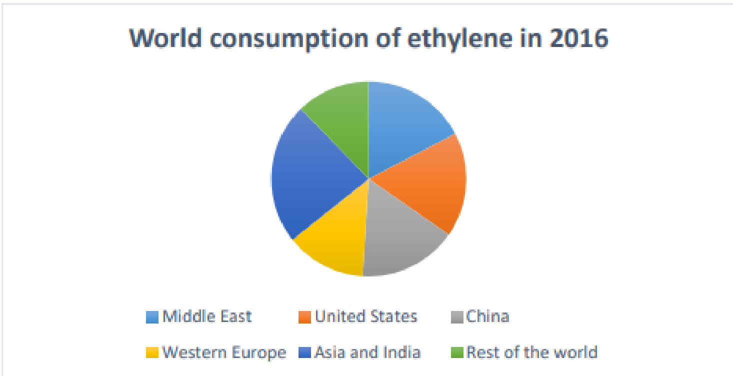

Figure 1. World consumption of ethylene in 2016.

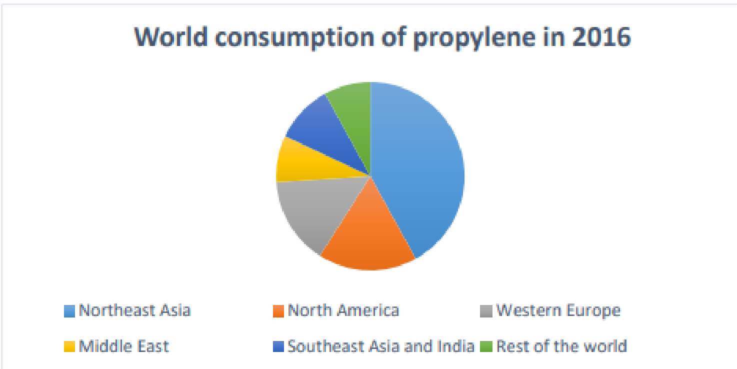

Figure 2. World consumption of propylene in 2016.

China dominates the consumption of methanol with over 60% of the market (IHS, 2016c). The world's largest producers of ammonia are China, India, Russia, the United States, Indonesia and Trinidad & Tobago with over 60% of global production (CAT, 2018).

Scoring and rating of chemicals

The estimates for the waste generation, recycling and incineration of chemicals are based on collected data and several assumptions. In 2016, polyethylene accounted for nearly 62% of total ethylene consumption (IHS, 2017). Similarly, polypropylene accounted for nearly 71% of total propylene consumption in 2015 (IHS, 2016a). We assumed no waste generation, zero recycling and 2% incineration (process flaring) for ethylene and propylene. All ammonia is utilized without recycling or incineration. We have not been able to track the waste generation, recycling or incineration for urea. Methanol is a multipurpose chemical and fuel (IHS, 2016c). We assumed no direct waste generation or recycling, but 20% incineration for methanol as a fuel. Plastic resin and fibre waste generation accounted for 74.2% of total polymer production in 2015. The waste generation for different plastics is taken from Geyer et al. (2017). The recycling and incineration of plastics vary considerably depending on the geographical location. Detailed global data on recycling and incineration for different non-fibrous plastics is scattered and scarce. We assumed 18% global recycling and 24% global incineration rates, in line with Geyer et al. (2017) for 2014. PVC is practically not recycled (only 0.5 Mt in Europe), and no data is available on its incineration. PE, PP and PET are most common in packaging materials and more easily recycled. PS and PUR are seldom recycled and thus we assumed zero recycling and 24% incineration. PP&A fibres are practically all landfilled or incinerated, and we assumed 11% incineration on the global scale (Kaza et al., 2018). Production of recycled fibres exists in small quantities, e.g. recovered from plastic waste in the oceans. The volumes of waste generation, recycling and incineration of chemicals are illustrated in Table 2. Total primary non-fibrous plastic waste generation accounts for 232 Mt in Table 2, nearly 53% of which consists of packaging waste according to the estimates of Geyer et al. (2017).

Table 2. *Waste generation, recycling and incineration of key bulk chemicals in Mt yr^{-1}.*

Chemical	Waste in Mt yr^{-1}	Recycled in Mt yr^{-1}	Incinerated in Mt yr^{-1}
Ammonia	0	0	0
Methanol	0	0	19
Urea	n.a.	n.a.	n.a.
Ethylene	0	0	4
Propylene	0	0	2
HDPE	40	7	11
LD&LLDPE	57	13	15
PP	55	13	14
PS	17	0	4
PVC	15	0	n.a.
PET	32	8	8
PUR resins	16	0	4
PP&A fibres	42	0	5

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The values from Table 2 were used to rate the chemicals. The rating of the chemicals is the result of calculations using Eq. 1. The values in bracket are the resulting scores. Ammonia was rated first (175), ethylene second (173), polypropylene and PP&A fibres joint third (96), fourth was propylene (94), LD&LLD polyethylene fifth (93), methanol sixth (76), HD polyethylene seventh (74), polyvinylchloride eighth (53), polyethylene terephthalate ninth (49), polyurethane resins tenth (39) and polystyrene eleventh (38). Urea has no rating due to insufficient data. The lowest rated, polystyrene, is utilized mainly for single-use food packaging (30%) and in the building and construction sector (29%). Polyurethane resins have several applications, the most important of which is in the building and construction sector (29%). The end use of polyethylene terephthalate is plastic bottles and other packaging (99%). The building and construction sector consumes 67% of all polyvinylchloride produced. HD polyethylene is mainly used for packaging (57%) and in the building and construction sector (20%). The packaging sector consumes nearly 68% of the LD&LLD polyethylene produced, and the share of consumer & institutional products is 14.5%. Clothing and fabrics manufacturing consumes practically 100% of the PP&A fibres produced. Polyester, the key component of which is PET, accounts for 70% of all PP&A fibre production. The consumption of polypropylene is divided as follows: 39% packaging, 19% consumer & institutional products, 12% transportation and 20% other uses. The key consumption patterns of plastics, listed above, are adapted from Geyer et al. (2017). The majority of ethylene (64%) and propylene (71%) is used in PE and PP polymer production. Ethylene derivatives include ethylene oxide (15%) and ethylene dichloride (9%). The former is primarily for PET production via ethylene glycol, and the latter is for PVC production via vinyl chloride. Other derivatives for propylene are propylene oxide (8%), acrylonitrile (6%), cumene (4%) and acrylic acid (4%), (IHS, 2017, IHS, 2016a). Methanol has several end uses: 18% for ethylene and propylene (methanol-to-olefins or MTO), 27% for formaldehyde and 20% for gasoline and fuel blends (IHS, 2016c). Urea production accounts for over 50% of total ammonia consumption and fertilizer use accounts for around 80-85% of urea consumption (IHS, 2016b). In addition to urea, ammonia is used to make nitric acid, ammonium nitrate, ammonium phosphate and hydrogen cyanide. The latter is used to produce methyl 2-methylpropenoate, a key monomer for the manufacture of various acrylic polymers. Direct use of ammonia is mainly in the mining and metal manufacturing industries and in industrial refrigeration (ECI, 2016).

3.2. Evaluation of technological choices

The technological evaluation started with the analysis of the production routes of selected chemicals. Different technological options, both upstream and downstream of the supply chain, were evaluated, taking into account the specific consumption patterns of each chemical. The assessment included substitution, reuse, material recycling, waste-to-energy and conversion technologies. In particular, the possibilities for increased direct recycling, change to renewable resources and resource-efficient technologies were highlighted. Urea was excluded from the technological evaluation due to the lack of data on waste generation, recycling and incineration.

Upstream options

The primary chemicals ammonia, ethylene, propylene and methanol do not generate physical long-life waste (in normal use and excluding accidents) in the environment, only emissions into the atmosphere. Therefore, direct recycling, reuse and waste-to-energy are not realistic options for these chemicals. Changing to renewable resources and utilizing resource-efficient technologies are the best options for achieving better material efficiency and reduction in the use of fossil resources. Development of alternative, substitute materials for plastics is also a downstream option worth considering as a long-term solution. Similarly, chemical recycling of plastic waste, i.e. as a feed stream for petroleum refineries or other chemical treatment facilities, is a realistic downstream option available before 2030.

Traditionally, ammonia is produced from natural gas (methane CH_4) and the process is energy-intensive. China produces methane by coal gasification. Green ammonia technology, using air, water and renewable electricity, is under development and expected to be piloted by 2025 (AI, 2019). Similarly, methanol is produced from natural gas or coal. New methanol technologies include production from carbon dioxide (CO_2) and hydrogen (H_2), and from renewable forest resources (Räuchle et al., 2016; Andersson et al., 2014; Melin et al., 2016). Ethylene is produced in petroleum refinery cracking units using crude oil and natural gas as primary resources. Bio-based ethylene is produced from bioethanol, especially in Brazil, where its principal use is in the production of bio-based polyethylene plastic. Propylene is produced by the propane dehydrogenation units of petroleum refineries and other on-purpose units (IHS, 2016a). We have not been able to locate any bio-based propylene production units.

Downstream options

Plastic resins and fibres, i.e. HD and LD&LLD polyethylene, polypropylene, PP&A fibres, PVC, PET, PU resins and PS, all generate long-life waste in the environment. Therefore, direct recycling, reuse, substitution with renewable materials, material's use reduction and waste-to-energy solutions are the primary options for material efficiency and reduction in the use of fossil resources. The current waste generation of these plastics equals 274 Mt yr^{-1} and recycled and incinerated waste amounts to 102 Mt yr^{-1} (Table 2). Consequently, maximal additional recyclable waste amounts to 172 Mt yr^{-1}. We evaluated the near-term potential for improving recycling, starting from the consumption pattern of each non-fibrous plastic. We combined the polymer-specific end-use data per market sector with the sector-specific waste generation data from Geyer et al. (2017) and deducted the current polymer-specific incineration and recycling volumes (Table 2) from the obtained values. The additional potential for near-term recycling of non-fibrous plastics amounts to 86 Mt yr^{-1}, and that of fibres to 8 Mt yr^{-1}. In addition, we calculated the maximal additional recyclable plastic waste values from Table 2. The maximal and near-term potential additional recyclable waste volumes are illustrated in Figure 3.

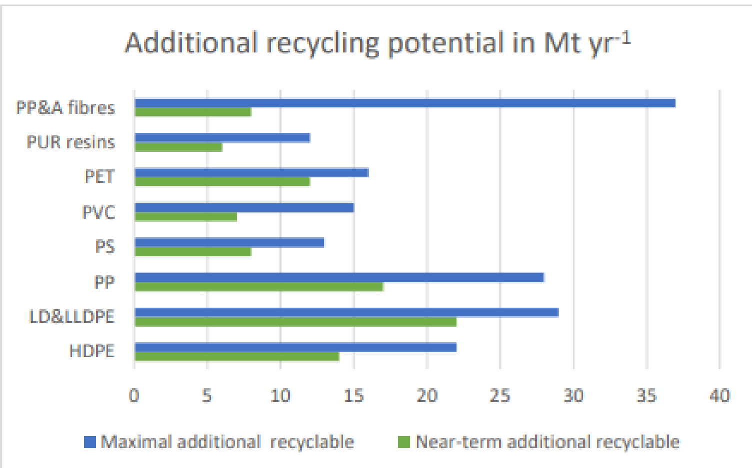

Figure 3. *Additional recycling potential of plastics in Mt yr^{-1}.*

The plastic waste generation rates differ considerably by market sector (Geyer et al., 2017), with the highest waste

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generation in the packaging (97%) and the consumer and institutional products (88%) sectors, and the lowest rates in the building and construction (20%) and in the industrial machinery (33%) sectors. Similarly, plastic waste generation differs by polymer type: LD&LLD polyethylene (89%), HD polyethylene (77%), polypropylene (81%), polystyrene (67%), PVC (39%), PET (97%), PUR resins (59%) and PP&A fibres (71%).

Our estimates indicate that improving near-term recycling (the values shown in brackets are additional volumes eligible for recycling) is easiest for packaging materials, i.e. LD&LLD polyethylene (22 Mt yr^{-1}), HD polyethylene (14 Mt yr^{-1}), polypropylene (17 Mt yr^{-1}) and PET (12 Mt yr^{-1}). Additional recycling or incineration of polystyrene (8 Mt yr^{-1}) is also possible. PVC (7 Mt yr^{-1}) would need partial, and PUR resins full (6 Mt yr^{-1}) chemical recycling.

Additional recycling of packaging plastics would require that the current poor recycling practices, especially in Northern America, Southeast Asia and the Indian subcontinent, are eradicated and new, segregated plastic waste collection and recycling practices, like those in Germany, are widely introduced. Better regulation of the global plastic waste export trade would reduce the amount of poorly recyclable, low-quality waste. Increased recycling and reuse of plastics would allow more time to develop replacement technologies for plastics, with alternative, preferably renewable materials that have positive impacts on the environment.

3.3. Life cycle analysis

This study is completed with a robust life cycle estimate of the greenhouse gas emissions of the potentially best options for reducing virgin material consumption and greenhouse gas emissions in the supply chain of each chemical.

Key inventory data and assumptions

The global GHG and CO_2 emissions are taken from UNEP (2018). We calculated the corresponding chemical sector emissions using the percentages of global emissions given in IEA et al. (2013). We assumed that these were unchanged between 2013 and 2018 for the chemical industry on the global scale. The ammonia production emissions are from CAT (2018), and present a rough minimum estimate of 2 t CO_2eq/tonne ammonia. The units producing ammonia from residual oil in India emit 2.8 t CO_2eq/tonne ammonia (IPPC, 2006). We estimated the global methanol GHG emissions separately for China (Su et al., 2013) and the rest of the world (Matzen et al., 2015; Kajaste et al., 2018). The assumption is that the new methanol production facilities in China installed after 2013 use cleaner coal technologies with cradle-to-gate GHG emissions of 3 tonne per tonne of methanol produced instead of the generally referred to 5.3 t CO_2eq/tonne methanol (Su et al., 2013; IPPC, 2006). The GHG estimates for ethylene production are from IPPC (2006) and Ghanta et al. (2014). The latter assumes that the energy used for ethylene production originates from natural gas or ethane. The GHG emissions of ethylene production using the steam cracking of naphtha and ethane amount to 1,135 kg and 840 kg CO_2eq/tonne of ethylene, respectively. The emission coefficients of IPPC for ethylene are higher: naphtha 1,730, gasoil 2,290, ethane 950 and propane 1,040 (all in kg CO_2eq/tonne of ethylene). We assumed 60% ethylene production from naphtha, and accordingly 40% from ethane (Levi and Cullen, 2018), and used the IPCC values for emissions. Correspondingly, we assumed 60% propylene production from naphtha, and accordingly 40% from on-purpose refinery units for olefins, using IPCC values for emissions and assuming propane emission values for the on-purpose units. Equally probable would be the selection of gasoil for propylene production. This would result in higher GHG emissions in the production chain of propylene. The key LCI data is shown in Table 3. The global chemical sector GHG emissions amount to 3, 444 Mt yr^{-1} and the summed GHG emissions of ammonia, methanol, ethylene and propylene total 989 Mt yr^{-1}, corresponding to 29% of chemical sector emissions.

The figures for plastic resin and fibre GHG emissions are not readily available. The GHG emissions of PVC production in the EU are 2,800 kg CO_2eq/tonne of PVC where 89% of the production is PVC bulk and the remaining 11% is PVC latex. The share of polymerization is 352 kg CO_2eq/tonne of PVC (Boulamanti and Moya, 2017). Generally, long-life plastics are considered to be fossil carbon sinks (embedded CO_2 emissions only), provided that production emissions (cradle-to-gate) are included. The end-of-life incineration of plastics releases the embedded emissions. The incineration emissions are compensated partly by energy production of municipal waste incineration, which reduces the use of virgin fossil energy.

Table 3. *Key Life Cycle Inventory data.*

Data	Unit	Value	Reference
Global GHG emissions	Mt CO_2eq yr^{-1}	49 200*	UNEP (2018)
Global CO_2 emission	Mt CO_2eq yr^{-1}	37 000	UNEP (2018)
Chemical sector GHG emissions	Mt CO_2eq yr^{-1}	3 444	IEA et al. (2013)**
Chemical sector CO_2 emissions	Mt CO_2eq yr^{-1}	2 350	IEA et al. (2013)**
Ammonia GHG emissions	Mt CO_2eq yr^{-1}	350	CAT (2018)
Methanol GHG emissions	Mt CO_2eq yr^{-1}	248	own calculations
Ethylene GHG emissions	Mt CO_2eq yr^{-1}	251	own calculations
Propylene GHG emissions	Mt CO_2eq yr^{-1}	140	own calculations
Polyethylene GHG emissions	Mt CO_2eq yr^{-1}	276	own calculations
Polypropylene GHG emissions	Mt CO_2eq yr^{-1}	162	own calculations
PET GHG emissions	Mt CO_2eq yr^{-1}	108	own calculations
PVC GHG emissions	Mt CO_2eq yr^{-1}	106	own calculations
PUR GHG emissions	Mt CO_2eq yr^{-1}	113	own calculations
Polystyrene GHG emissions	Mt CO_2eq yr^{-1}	83	own calculations
PP&A fibres GHG emissions	Mt CO_2eq yr^{-1}	n.a.	n.a.

*excluding emissions from land use change (LUC). **percentage of global emissions.

The embedded emissions of PET amount to 2.04 kg CO_2eq /kg, and those of PE and PP are 3.14 kg CO_2eq /kg. The total cradle-to-product (plastic tray and PE film) emissions of PE and PP amount to 2.38 kg CO_2eq /kg. Accordingly, PET cradle-to-product (plastic tray) emissions are 3.26 kg CO_2eq /kg (Patel et al., 2018). Styrene production emissions are 887 kg CO_2eq/tonne of styrene (Boulamanti and Moya, 2017). The GHG emissions from polystyrene production are 3,300 kg CO_2eq/tonne and those from PUR 4,200 kg CO_2eq/tonne (Ruuska, 2013).

The European Union (EU) has benchmarked chemical sector performance on GHG emissions. The benchmark values relate to 10% of the best industry performers in the EU. These values indicate improvement potential in reducing GHG emissions in the production of chemicals when best available technologies (BAT) are implemented. The EU benchmark values in kg CO_2eq/tonne of product are 1,618 for ammonia, 702 for ethylene and propylene, 155 for aromatics, 512 for ethylene oxide, 527 for styrene, 204 for vinyl chloride, 85 for PVC and 238 for PVC latex. The three last in the list do not include electricity emissions (Boulamanti and Moya, 2017).

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Upstream impact

The first step to improve the GHG balance of ammonia, ethylene and propylene would be to strive for the EU benchmarked values of GHG emissions on the global scale. For ammonia, this would mean a reduction of 382 kg CO_2eq/tonne of ammonia produced. Correspondingly, for ethylene and propylene the reduction would be 716 kg CO_2eq/tonne of ethylene and 756 kg CO_2eq/tonne of propylene. These and all other upstream GHG impacts of improved resource efficiency on the global scale are illustrated in Figure 4. Green ethylene production from corn ethanol reduces GHG emissions only if the energy used in the process is from renewable sources. This is because its production is highly energy-intensive, including H_2 production in the ammonia fertilizer manufacture and the dehydration of ethanol with consequent water separation. Corn photosynthesis only partly offsets these emissions by CO_2 removal from the atmosphere. Assuming natural gas as the energy resource in green ethylene production, the cradle-to-gate GHG emissions amount to 1347 kg CO_2eq/tonne of ethylene (Ghanta et al., 2014). The use of natural gas as the energy resource contributes almost 85% of the GHG emissions. Consequently, green ethylene production utilizing only renewable energy resources would reduce the GHG emissions to 202 kg CO_2eq/tonne of ethylene. Increasing the production of green ethylene, and in the future also green propylene, with fully renewable energy would reduce, accordingly, the current GHG emissions by an astounding 1,216 kg CO_2eq/tonne of ethylene and 1,256 kg CO_2eq/tonne of propylene. However, we consider this not to be a near-term option.

Methanol production has no EU benchmark. Currently the lowest GHG emissions of methanol production are in Sweden and amount to 462 kg CO_2eq/tonne of methanol. The methanol production from captured CO_2 and renewable H_2 delivers a negative emission of -752 kg CO_2eq/tonne of methanol. The highest negative emission amounts to -914 kg CO_2eq/tonne of methanol produced from forest biomass (Kajaste et al., 2018). Consequently, switching the current methanol production to the GHG emission level of methanol in Sweden would reduce GHG emissions by 2,148 kg CO_2eq/tonne of methanol.

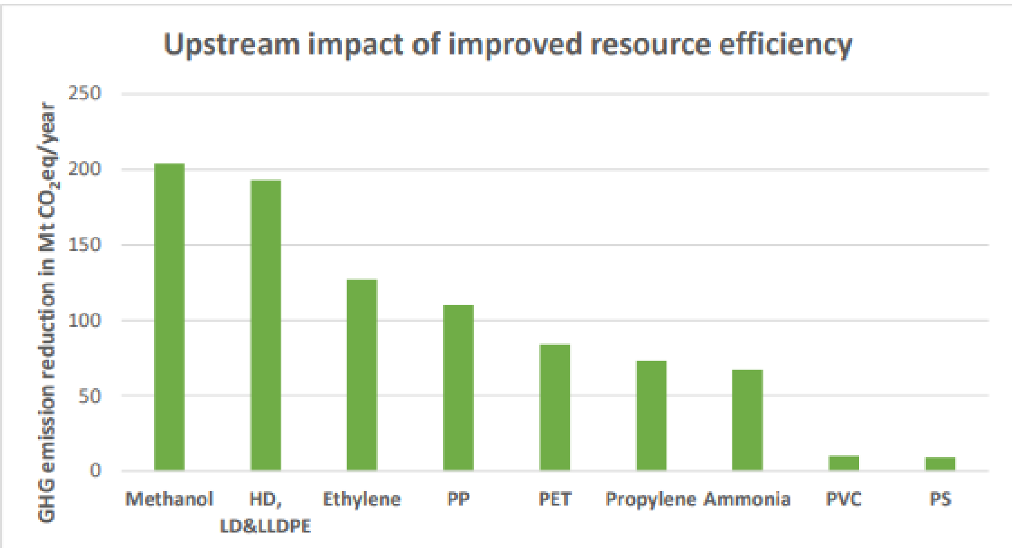

Figure 4. *Upstream GHG impact of improved resource efficiency in Mt CO_2eq yr^{-1}.*

Accordingly, captured CO_2 and renewable H_2 technology would reduce GHG emissions by 3,363 kg CO_2eq/tonne of methanol, and forest biomass technology by 3,525 kg CO_2eq/tonne of methanol. To conclude, the upstream options are readily available for implementation if the financial and political benefits lower the threshold to start GHG reductions in the chemical sector.

Applying the same ethylene and propylene emission reduction targets for the cradle-to-product (plastic tray and PE film) emissions of PE and PP, it is possible to reduce the emissions by 1,664-1,624 kg CO_2eq /tonne. Accordingly, the PET cradle-to-product (plastic tray) emission reduction would be 2,544 kg CO_2eq /tonne. Assuming the same global PVC production profile as in the EU (89% PVC bulk and 11% PVC latex) and applying the EU benchmark values for PVC, it would be possible to reduce the GHG emissions of polymerization from 352 kg CO_2eq/tonne of PVC to 102 kg CO_2eq/tonne of PVC.

With an annual global production of 38 Mt PVC, striving for the benchmark level would reduce the global GHG emissions from PVC production by 9.5 Mt CO_2eq yr^{-1}. Applying the EU benchmark for styrene production (527 kg CO_2eq/tonne) would also reduce the emissions for polystyrene by 360 kg CO_2eq/tonne, and the corresponding global emission reduction would be 9 Mt CO_2eq yr^{-1}. We have not been able to identify the global emissions of PP&A fibres. The identified upstream near-term possibilities for reducing the GHG impact of the chemicals selected for this study amount to 876 Mt CO_2eq yr^{-1}. This would mean a 25% reduction of all global chemical sector emissions. However, the probability for all global production facilities to reach the EU benchmarked values is unclear.

Downstream impact

The estimation of GHG emission reductions from improved recycling (near-term additional recyclable, see Figure 3) would require detailed analysis of the recycling value chain of each polymer, which is beyond the scope of our study. Therefore, we performed only a robust estimate of GHG emission reductions. Incineration of waste plastics also releases the embedded CO_2 emissions. The production of energy reduces the GHG impact of incinerated plastics. The GHG emissions from incineration of PET trays is 2,000 kg CO_2eq/tonne, and 1,300 kg CO_2eq/tonne by avoiding the use of fossil energy. Accordingly, the mechanical recycling of PET trays has GHG emissions of 150 kg CO_2eq/tonne, and negative emissions of 2,350 kg CO_2eq/tonne by avoiding the use of virgin material. Similarly, mechanical recycling of mixed plastics emits 800 kg CO_2eq/tonne, and would have negative emissions of 500 kg CO_2eq/tonne by avoiding the use of virgin material. In general, the recycling losses from incineration would amount to 1,700 kg CO_2eq/tonne by avoiding the use of fossil energy (data from Bergsma, 2019). Hence, mechanical and chemical recycling of plastics should be favoured. A robust estimate for the avoided GHG emissions of mixed mechanical recycling of HD-PE, LD&LLD-PE, PP and PET in the near term (Figure 3) would mean 75 Mt yr^{-1} of additional recycled plastics with annual avoided GHG emissions of 37.5 Mt CO_2eq. Improved segregation of plastics recycling would considerably increase the amount of avoided GHG emissions: for 12 Mt yr^{-1} recycled PET the GHG saving alone would be 28 Mt CO_2eq. Assuming the same relation between virgin product emissions and segregated recycled production emissions as for virgin and segregated recycled PET, negative emissions of 1,716 kg CO_2eq/tonne is possible for recycled HD-PE, LD&LLD-PE and PP by avoiding the use of virgin material. This would give avoided GHG emissions of 108 Mt CO_2eq annually on the global scale with an additional recycled volume of 63 Mt yr^{-1}. The recycling of PVC is challenging; it is assumed that the annual quantity of products that can be considered as substitutes for virgin PVC consists of 90% pre-consumer waste and 10% post-consumer waste. The recycling rate of PVC waste in the EU reached 16% in

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2014, and the average GHG emissions of recycled PVC totalled 1,900 kg CO_2eq/tonne, a saving of 900 kg CO_2eq/tonne compared to virgin PVC (Boulamanti and Moya, 2017). We assume that it is possible to reach the same PVC recycling rate on the global scale as in the EU. The avoided GHG emissions of additionally recycled PVC would be 6.3 Mt yr^{-1}. We have not been able to estimate the GHG savings from additional recycling of PUR, PS or PP&A fibres. The identified downstream near-term recycling possibilities for plastics would reduce the GHG impact by 142.3 M CO_2eq t yr^{-1}. This would mean an additional 4% reduction of all global chemical sector emissions. The downstream GHG impacts of recycling on the global scale are illustrated in Figure 5

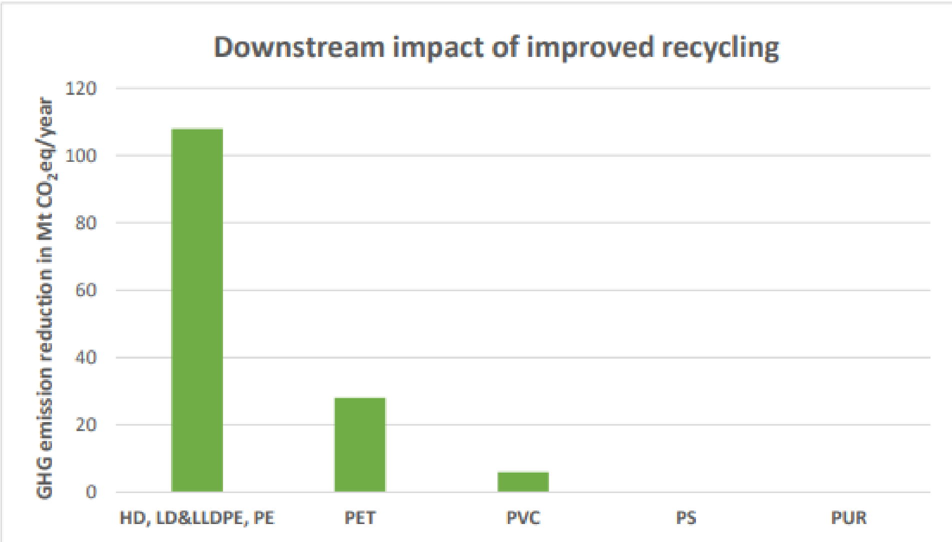

Figure 5. *Downstream GHG impact of improved recycling in Mt CO_2eq yr^{-1}.*

Sensitivity and limitations of the results

We have based our study on references and several assumptions about them. Therefore, our results should be considered with a degree of caution, especially concerning the additional recycling amounts of plastic waste. The robust life-cycle estimates of GHG emissions use published emission values. We have assumed that the LCI values based on references have a maximum confidence interval of between +5 and -5%. We assume no serious overlapping of downstream and upstream GHG emissions. Our average emissions for the plastics production chain are 4,194 kg CO_2eq/tonne when the WWF average estimate is 5,051 kg CO_2eq/tonne of plastics (WWF, 2019). The total upstream impact of resource efficiency (876 Mt CO_2eq yr^{-1}) is the upper limit of resource efficiency measures without bioplastics or renewable ammonia, methanol, ethylene and propylene, and can be reached incrementally.

4. Conclusions

Focusing on improved technological processes for ammonia, methanol, ethylene, propylene, PE, PP, PET, PS and PVC has the potential to reduce global greenhouse gas emissions by 876 Mt CO_2eq yr^{-1}, provided that all of the current global production is upgraded to the level of the European Union's benchmarked facilities. These upstream improvements in resource efficiency would mean a 25% reduction of all global chemical sector emissions.

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However, the probability for all global production facilities to reach the EU benchmarked values is unclear. Even an incremental 10% improvement in the efficiency of upstream supply chains would reduce GHG emissions by 88 Mt CO_2eq yr^{-1}. On the downstream side, increasing the recycling rate of non-fibrous plastic resins from the current 18% to 42% would reduce global greenhouse gas emissions by 142.3 Mt CO_2eq yr^{-1}, provided that incineration is not increased and that the segregation of recycling is improved. These downstream improvements in recycling would mean an additional 4% reduction of all global chemical sector emissions. Better regulation of the global plastic waste export trade would reduce the amount of poorly recyclable, low-quality waste. Increased recycling and reuse of plastics would allow more time to develop replacement technologies for plastics, with alternative, preferably renewable materials with positive impacts on the environment. This study estimates the near-term possibilities to reduce the GHG impact for both the upstream and downstream supply chains of key chemicals. The implementation would require both financial resources from the chemical industry and political will from governments. Future research needs include a detailed LCA assessment of the supply chain of each chemical, complemented by investment cost estimates of the best options to improve resource efficiency and manage GHG emissions.

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Treatment of wastewater from textile whitening with a coagulant based on *Moringa Oleifera*

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Abstract

Optical Brighteners (OBs) are a type of dyes that can be found in textile whitening wastewater. OBs are colourless and can't be seen with a naked eye; nevertheless, they emit fluorescence when are exposed to ultraviolet light. OBs are poorly biodegradable and are only partially adsorbed by sludge in biological systems; therefore OBs can reach the environment. OBs are emerging organic pollutants. Besides OBs, textile wastewaters from whitening process used to have recalcitrant compounds, oxidizing agents, high salinity and high alkalinity.

Moringa Oleifera can be used as a natural coagulant in alkaline waters and, furthermore, its seeds contain high content of water-soluble proteins with coagulating properties. Also, *Moringa Oleifera* seeds contain around 30% of oil with an important commercial value. The waste cake from *Moringa Oleifera* oil extraction can be collected and used as a coagulant. In this work the removal of OB from whitening wastewater was studied. This study shows that the textile whitening wastewater can be treated successfully with this natural coagulant.

Initially, the removal of OB solutions was tested using a coagulant solution of *Moringa Oleifera*. "Fluorescent Brightener 134" (OB), a diaminostilbenedisulphonic acid derivative, was selected. The OB solutions at 100 and 1000 mg/L were tested. Moringa coagulant solutions were made from moringa seeds milled and degreased. Optimal dosage test was made by Jar-test with this coagulant. The OB removal was analysed based on the absorbance and based on the organic load. Removal up to 72% of the OB was obtained. Also, was observed that the moringa coagulant had good performance at pH higher than 4. The optimal ratio "moringa coagulant concentration respect to OB concentration in water" was 4:1.

Hereafter, whitening wastewater was obtained from optical-chemical whitening made at the laboratory. Optical-chemical whitening was performed with 100% cotton fibre and OB at 1000 mg/L. Then, the whitening residual bath water with OB was collected and treated with moringa coagulant. It was removed more than 50% of OB from the residual water. It was observed that the presence of oxidizing substances did not affect the effectiveness of the moringa coagulant.

Finally, it is possible to recover the supernatant of the treated water and reuse it in new textile processes. The whitened fibres were analysed and good results of whiteness and hue were obtained. It was possible reuse the water and residual reagents. This would minimize the expenses and the water footprint of the whitening process.

Keywords: *Moringa Oleifera*, Optical Brighteners, Natural Coagulants, Textile Wastewaters.

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1. Introduction

The optical brighteners (OBs) are colourless chemical compounds which have the property of absorbing ultraviolet light (340-360nm) and reemit it partially as fluorescent visible light, generally in the blue spectral region (440-460nm) (Bueno et al., 2017; Guo et al., 2017). Such compounds are commonly used in the textile, paper and plastic industries to improve the whiteness of the materials and counteract their yellowish colour. For the same purpose, (OBs) are also added in multiple products such as photographs, pelts, paints, printing inks, adhesives, circuit boards and home appliances, etc. (Karmakar, 1999). Recently, another important application for OBs has been found: they protect clothing and human skin from the UV solar radiation (Algaba et al., 2007).

In the textile industry, OBs can be applied to all types of fibres, although they are mainly used in the bleaching of natural fibres, such as cotton, which have beige and yellowish tones. In these cases, chemical bleaching with an oxidizer is usually carried out first or simultaneously. Hydrogen peroxide (H_2O_2) is the most widely used oxidizer, which has replaced sodium hypochlorite because it is less polluting. However, H_2O_2 provides lower whiteness and it is usually combined with an OB to improve the whiteness of the product (Karmakar, 1999; Ministerio de Medio Ambiente, 2004). The OBs preferred by the textile industry are those that allow preserving the whiteness of the fibres for as long as possible. It is expected that OBs have high resistance to oxidizing products, high stability to sunlight and high solubility (Bueno et al., 2017). The most frequently used are the stilbene, benzoxazole, and coumarin and pyrazolines derivatives, with stilbene derivatives being the most common in the market (Karmakar, 1999; Tiki et al., 2010; Kramer et al., 1996)

The stilbene type OBs are based on a structure of aromatic groups with a central carbon-carbon double bond system. They also have electron donor groups, such as -OH or -NH_2, among others. The stilbene type compounds can be found in two isomeric forms. The trans isomer is the only one that acts as OB, since it is fluorescent. By action of natural light, it passes to the cis form, which produces a yellowing of the textile fibres due to the loss of fluorescence of the BO. Isomerization is reversible and has a dynamic equilibrium (Guo et al., 2017; Karmakar, 1999; Tiki et al., 2010).

A fraction of the added OB is also lost due to partial photodegradation. In addition, a significant amount of OB is discharged during the washing of the fibres, becoming part of the wastewater (Bueno et al., 2017; Tiki et al., 2010)In general, the textile sector has an important impact on the environment, especially in the water environment, since it generates a large amount of wastewater (Ministerio de Medio Ambiente, 2004; Ercin and Hoekstra, 2016) Textile bleaching wastewater usually has a highly alkaline pH and may also contain OBs, in addition to other recalcitrant substances. Although OBs are used at low concentrations and have low toxicity, they are difficult to remove because they are poorly biodegradable. In biological treatment plants they are partly adsorbed by sludge, which may affect the microbial activity of these biological systems (Kramer et al., 1996; Salas et al., 2019) Another part can remain dissolved in the treated water and taking into account that the OBs are persistent pollutants and undetectable to the naked eye, they can reach to extend and remain in the environment. Several publications highlight the presence of OBs in surface waters and in aquatic sediments (Rachel et al., 2002; Assaad et al., 2014; Poiger et al., 1998, 1999) This could have a very negative impact on aquatic organisms since some of these compounds can potentially be carcinogenic and mutagenic (Assaad et al., 2014; Jung et al., 2012)

The removal of residual OBs present in the water has been the subject of several studies. They have been treated mainly by advanced oxidation processes (Yu et al., 1998; Philip et al., 2003), photo-induced degradation (Wong-wah-chung et al., 2003) and liquid-liquid extraction (Han et al., 2017). However, some of these methods are difficult to apply at an industrial level due to their high cost and, in addition, they could occasionally generate intermediate products whose toxicity is unknown (Philip et al., 2003; Han et al., 2017)

Coagulation- flocculation is an economic and easy to apply method to remove OBs from wastewater. However, the conventional coagulants (alum, ferric chloride and ferrous sulphate) have the disadvantage of generating sludge with a high content of metals, which could lead to neurological diseases (Bhatia et al., 2007). Therefore, this paper proposes the elimination of OBs from textile wastewaters by means of a natural coagulant, in a way that the sludge generated by this method does not contain salts or metal hydroxides. Specifically, a residue, obtained from the extraction of the oil from the *Moringa Oleifera* seeds, has been selected as coagulant. The extracted oil (20-30%) is highly appreciated for its applications in the cosmetic, pharmaceutic and other industries. *Moringa Oleifera* seeds have been used successfully as coagulants to purify drinking water (López- grimau et al., 2013; Amante et al., 2016) and to remove dyes. Its efficiency in these processes is attributed to the large amount of coagulant proteins contained in the residual cake, once the oil has been extracted (Bhatia et al., 2007; Vilaseca et al., 2014; Salas et al., 2018)

The residues of *Moringa Oleifera* seeds have clear advantages over traditional coagulants. In addition to the absence of metals, it should be noted that *Moringa Oleifera's* coagulant is efficient at a wide pH range, including highly alkaline media typical of whitening wastewater, while the performance obtained with conventional chemical coagulants highly depends on pH.

Finally, it has been reported that wastewater from textile dye treated with *Moringa Oleifera* can be reused, both water and residual reagents, to perform new dyeing processes (Vilaseca et al., 2014; Salas et al., 2018; López- Grimau et al., 2016). In this study the viability of reusing the residual water of whitening, purified by residues of *Moringa Oleifera* seeds, is evaluated. To this end, the quality of the fibres whitened with reused water was compared respect to the quality of the fibres whitened with decalcified water. The whiteness degree of the fabrics is determined and the results obtained are discussed.

2. Methodology

2.1 Materials

In the tests carried out in the laboratory, coagulant products were used. The *Moringa Oleifera* coagulant, Aluminium Sulphate and TIDEC 700 were selected for the treatment of optical brightener solutions.

The seeds with shell of the *Moringa Oleifera* plant were purchased; these seeds came from Burkina Faso. Before *Moringa Oleifera* coagulant solution was prepared, moringa oil extraction was done. The seeds, without husk, were grinded with a commercial electric grinder. Then, the oil from the ground seeds was extracted by soxhlet extraction with ethanol (96%) for 2 h. The defatted moringa seed was dried in an oven at 60ºC for 24 h. In the same way, the extracted moringa oil was dried for 72 h. It was possible to extract 25% ± 9% by weight from moringa seed oil.

The *Moringa Oleifera* coagulant was prepared with the residual cake. A 5% m/v moringa solution was prepared with distilled water under rapid stirring for 2 h to extract water-soluble coagulant proteins. A moringa coagulant solution with suspended particles was obtained.

Aluminium Sulphate [$Al_2(SO_4)_3$], (98 -100% richness) of Panreac brand, was prepared in 5% m/v solutions with distilled water under rapid stirring for 10 minutes until a homogeneous solution was obtained. The TIDEC 700 is a synthetic coagulant provided by the company T.I.D.E. 2000, S.L. It is a dicyandiamide- based coagulant in

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aqueous solution (CAS 55295-98-2). In the same way as the previous coagulant, a solution in 5% m/v with distilled water was prepared.
The optical brightener used was Leucophor PC (Clariant Iberica, Sant Joan Despí, Spain) identified as L-PC. It is a product derived from diaminostilbene-disulphonic acid. It can be found in the Colour Index as Fluorescent Brightener N/A 134 (CAS 3426-43-5) (Society-of-dyers-and-Colourist, 2017).
The L-PC optical bleach solution was prepared at 100 mg/L in distilled water under rapid stirring for 15 minutes until a homogeneous solution was obtained. This concentration was chosen, because it can be evaluated by the spectrophotometric method without making dilutions. This method is explained in the next section.

2.2 Experimental method

2.2.1 OBs determination

OBs in water samples were analysed by two different methods: 1) UV-Vis spectrum and 2) organic load,

1.UV-Visible spectrum analysis was done to evaluate the concentration of optical brighteners in the water samples; it was analysed using a Shimadzu UV-2401PC spectrophotometer. The behaviour of the spectrum when exposed to natural light over time was studied to identify the working wave length; considering that the maximum duration of the testing was 24 hours. Different solutions of L-PC were made at 100 mg/L, which were analysed from 190-450 nm, due to this wave range it was possible to obtain the full spectrum of the optical brightener. Three key wavelengths were identified, at 262 nm corresponding to the "trans" isomer (□max_1), then at 343.5 nm corresponding to the "cis" isomer (□max_2) and finally at 297 nm corresponding to the isosbestic point of the L-PC (□$I.P._{297}$). The wavelength at the isosbestic point is where the concentration of the "cis" and "trans" isomers of the L-PC are in equilibrium (Ion et al., 2008; Rachel et al., 2002).
An analysis of the absorbance at the isosbestic point, of optical brightener samples, was made to verify that it was not affected by natural light during testing. The variation of the absorbance in the wavelength of the isosbestic point (□297), of the 7 different control solutions (100 mg/L), was analysed at 30 min and at 24 h. The mean absorbance was 0.900 and 0.896 (□2 0.010) at 30 minutes and 24 hours respectively. Therefore the isosbestic point (297 nm) was selected as the working wavelength.

2. The organic load analysis was made to relate the removal of optical brightener with the reduction of organic load of the water sample. To analyse the organic load of samples obtained, the total organic carbon (TOC) was evaluated. The Total Organic Carbon Analyser, TOC-L Shimadzu was used based on standard EN 1484: 1997 (European Committee for Standardization, 1997). A calibration curbe was made at a maximum concentration of 100 mg / L of L-PC. The equation obtained was: Concentration $OB_{L\text{-}PC} = [(TOC_{Sample} - TOC_{Blank}) + 2.352] * (0.3341)^{-1}$, with a coefficient of correlation of 0.999. The results obtained by this method were compared with those obtained by the spectrophotometric method.
When it was not possible to evaluate the TOC or in the presence of particulate matter in the samples, the Chemical Oxygen Demand (COD) was determined. The COD was analysed by the dichromate method based on standard ISO 6060: 1989 (ISO, 1989).

2.2.2 OB removal tests in water with different coagulants

Coagulation-flocculation tests were performed using the different coagulants to determine the recommended dose for the elimination of optical brightener. Jar tests were performed with rapid agitation (10 min) followed by slow agitation (15 min). Tests were made at different coagulant concentration (50-600 mg / L) and samples were taken from the supernatant at different decantation times (0.5, 2, 4 and 24 h). The testing was made at alkaline pH (□10) since it is the typical pH of textile whitening wastewater. The pH adjustment was made with
0.1 N NaOH and HCl solutions.

From the supernatant samples obtained in the flocculation coagulation testing, UV-Vis spectrum and organic load were analysed to determine the OBs removal efficiency.

2.2.3 Treatment and reuse of waste water from whitening process

For the treatment of wastewater from the whitening process, a first whitening of cotton fibres was carried out to collect the wastewater. Afterwards, the collected water was treated with the *Moringa Oleifera* coagulant. Finally, the second whitening was performed to other cotton fibres using treated water.

First whitening process was done to recover the wastewater. The residual water with optical brightener was obtained in the laboratory by collecting the wastewater from an optical-chemical whitening made with clean water. This whitening process was based on a simplified recipe that is currently used in the industry. This first bleaching-whitening was done by exhaustion at a 1/10 bath ratio using the Ti-Color equipment. A bath volume of 100 ml, 10 g of scoured cotton fabric and 1% w.o.f. optical brightener were used. As a chemical oxidizing agent, 5 ml/L of H_2O_2 (50%) was used and the pH was adjusted to 10 using NaOH (50%). After the fibres were analysed with the CM-3600d, Konica Minolta spectrophotometer to evaluate the quality of the bleached fibres, hue and whiteness were assessed. The concentration of BO in bath water before and after bleaching was evaluated. Also was assessed the effect of H_2O_2 on the BO and on the fibre.

Then, the residual water of the whitening bath was treated. The water was evaluated before and after the jar test with the Moringa Oleifera coagulant. The water treated with this coagulant was analysed at 0.5 and 24 h of decanting.

After, the treated water was reused for a new whitening process. The supernatant of the treated water was recovered. This treated water is filtered with glass wool, then the concentration of optical brightener was adjusted to reach a concentration of OB equivalent to that used at the first whitening. The concentration of H_2O_2 was assessed (Roncero Vivero, 2001) and the concentration adjusted. The ratio of the reused water with the clean water was 70:30. The whitening-bleaching was carried out with the same methodology previously explained in the first whitening.

Finally, the quality of the bleached fibres was evaluated using the CM-3666d spectrophotometer and compared with the fibres of the first whitening. Hue CIE and CIE Whiteness were evaluated (ISO, 1997).

3 Results and Discussion

3.1 Removal of OB in simulated wastewater

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The results of effectiveness of the 3 different coagulants to remove OB from water were obtained. The percentage of removal based on spectrophotometric method is expressed as "Abs-%OB-Removal". On the other hand, the percentage of removal based on the organic load is expressed as "TOC-%OB-Removal". This last TOC-%OB-Removal value allowed us to confirm the elimination of BO.

To unify the results, a regression analysis was performed to establish a relationship between Abs-%OB- Removal and TOC-%OB-Removal. The TOC-%OB-Removal was considered the dependent variable and the Abs-%OB-Removal independent variable. Based on this statistic analysis the results were calculated, and these are expressed as "%OB-Removal-cal". This %OB-Removal-cal allows to determine, based on the data obtained by the spectrophotometric method, a percentage of elimination of OB closer to reality.

The statistics were made using the data analysis tool of Microsoft Excel.

3.1.1 Removal of OB with aluminium sulphate ($Al_2(SO_4)_3$)

The percentages of OB removal with $Al_2(SO_4)_3$ obtained are shown in Table 1 It can be seen that there is some similar behaviour of the Abs-%OB-Removal data and the TOC-%OB-Removal data.

Table 1. *OB removal with* $Al_2(SO_4)_3$ *based on absorbance (Abs %OB-Removal) and based on organic load (TOC %OB-Removal).*

	Abs-%OB-Removal				**TOC-%OB-Removal**			
$Al_2(SO_4)_3$ (mg/L)	**100**	**200**	**300**	**400**	**100**	**200**	**300**	**400**
0.5 h	12.1	18.5	9.2	0.0	14.6	16.5	17.4	15.0
2 h	44.7	49.6	24.9	6.9	21.8	26.1	20.9	16.4
4 h	54.8	59.3	39.4	20.5	25.2	28.4	23.3	18.1
24h	63.2	**66.3**	47.7	30.3	26.0	**28.4**	21.5	16.9

The Abs-%OB-Removal shows a removal up to 66.3% of OB using $Al_2(SO_4)_3$ to 200 mg. Whereas the TOC-%OB-Removal indicates that only 28.4% was removed at this same concentration of OB at 200 mg/L.

The statistical relationships between of TOC-%OB-Removal and Abs-%OB-Removal from table 1 was determinate by regression analysis. In this case, the data of Abs-%OB-Removal in relation to TOC-%OB- Removal have a multiple correlation of 0.935. This value indicates that there is a strong relationship between the data. The following relationship was established: %OB-Removal-cal = 0.2065*(Abs-%OB-Removal) + 13.979

Based on this model to calculate the %OB-Removal-Cal data. The relationship between TOC-%OB-Removal and Abs-%OB-Removal response obtained with the previous model is shown at Figure 1.

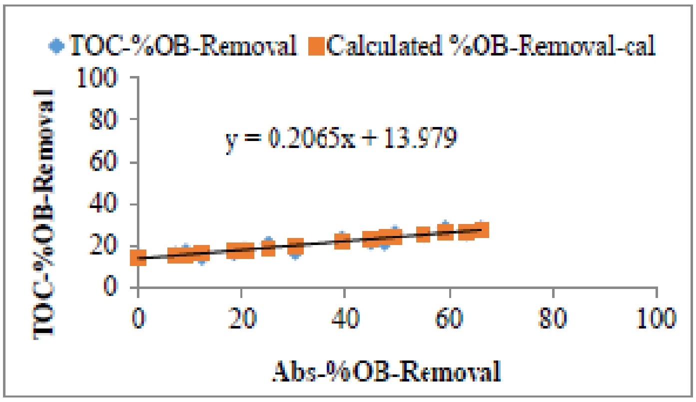

Figure 1. *Fitted line plot displays relationship between TOC-%OB-Removal and Abs-%OB-Removal response and calculated %OB-Removal (%OB-Removal-cal) with $Al_2(SO_4)_3$.*

Based on this relation the removal of OB was evaluated when the coagulant $Al_2(SO_4)_3$ was used. The results obtained in the %OB-Removal-cal have a direct relation with the TOC-%OB-Removal with a standard error of 1.75. The results of %OB-Removal-cal are shown in Figure 2.

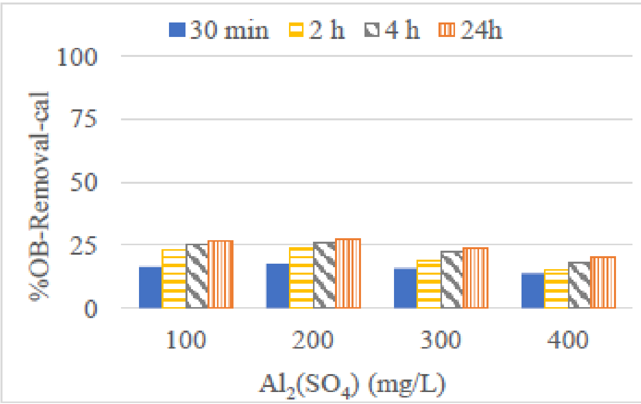

Figure 2. *Removal of OB with $Al_2(SO_4)_3$ (%OB-Removal-cal) . Initial OB concentration: 100mg/L.*

The coagulant $Al_2(SO_4)_3$ was inefficient for the elimination of OB L-PC since the maximum elimination was 28% at a dose of $Al_2(SO_4)_3$at 200 mg/L. It is known that $Al_2(SO_4)_3$ is effective to eliminate suspended solids, but failed to eliminate most of the diluted water BO.

3.1.2 Removal of OB with TIDEC:

The percentages of OB removal with TIDEC obtained are shown in Table 2, to compare Abs-%OB-Removal with TOC-%OB-Removal. Also in this case, it can be seen that there is some similar behaviour of the Abs-%OB-Removal data and the TOC-%OB-Removal data.

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***Table 2**. OB removal with TIDEC based on absorbance (Abs-%OB-Removal) and based on organic load (TOC-%OB-Removal).*

	Abs-%OB-Removal						TOC-%OB-Removal					
TIDEC (mg/L)	50	60	80	90	100	300	50	60	80	90	100	300
0.5 h	1.2	31.5	42.1	52.0	0.0	0.0	46.3	51.5	56.2	60.5	17.9	19.5
2 h	22.7	64.1	69.2	60.6	0.0	0.0	41.3	61.6	70.9	68.5	19.2	15.2
4 h	-	77.4	73.9	-	0.0	0.0	-	65.0	76.9	-	19.6	-
24 h	40.6	87.5	**89.2**	88.3	0.0	0.0	62.0	68.0	**75.8**	74.0	12.4	6.9

The Abs-%OB-Removal shows a removal up to 89.2% of OB using TIDEC at 80 mg/L. Whereas the TOC-%OB-Removal indicate that only 76% was removed using the same concentration of TIDEC at 80 mg/L.

It is observed in Table 2 that both Abs%-OB-Removal and TOC-%OB-Removal optimal dose of TIDEC was between 60 - 90 mg/L. It should be noted that at a higher doses (TIDEC at 100 - 300 mg/L) it is inefficient for the removal of OB in water.

The statistical relationships between of TOC-%OB-Removal and Abs-%OB-Removal from table 1 was determinate by regression analysis. In this case, the data of Abs-%OB-Removal in relation to TOC-%OB- Removal have a multiple correlation coefficient of 0.934, this means that they have a strong relation. The following relation was established: %OB-Removal-cal = 0.6945*(Abs-%OB-R) + 19.209

Based on this model to calculate the %OB-Removal-Cal data. The relationship between TOC-%OB-Removal and Abs-%OB-Removal response obtained with the previous model is shown at Figure 3.

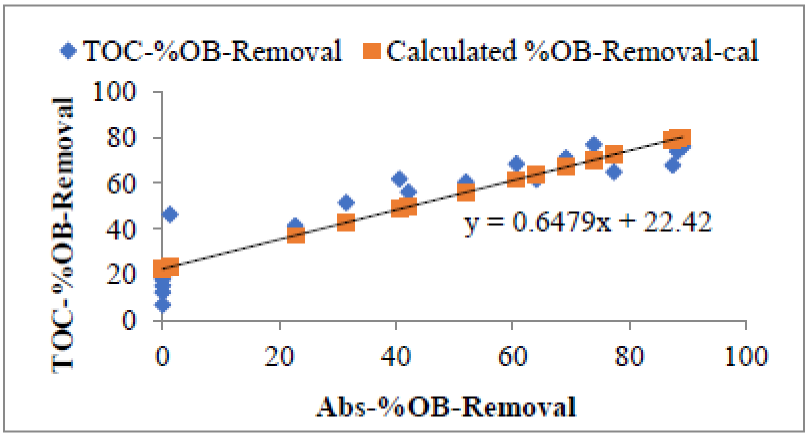

***Figure 3.** Fitted line plot displays relationship between TOC-%OB-Removal and Abs-%OB-Removal response and calculated %OB-Removal (%OB-Removal-cal) with TIDEC.*

The results of %OB-Removal-cal have a direct relationship with the TOC-%OB-Removal with standard error of 9.44. The results obtained from %OB-Removal-cal are shown in Figure 4.

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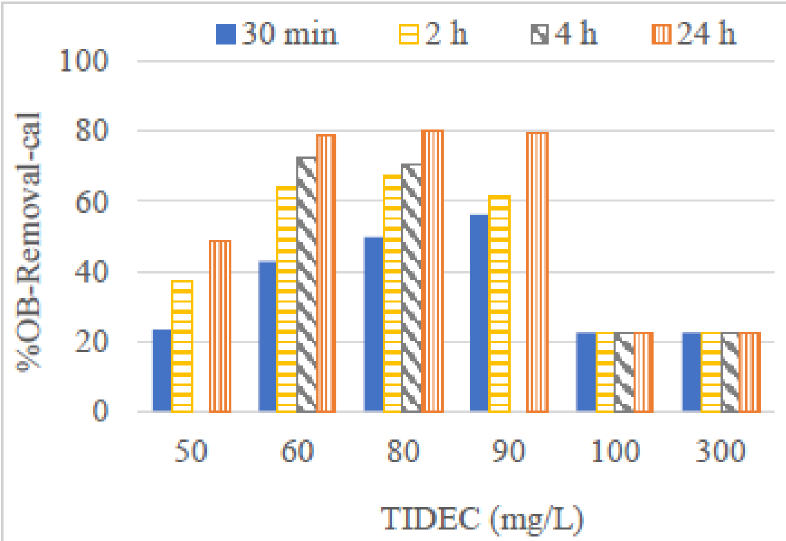

Figure 4. *Removal of OB with TIDEC (%OB-Removal-cal). Initial OB concentration: 100 mg/L.*

The TIDEC coagulant has certain limitations. Whereas low concentrations of TIDEC coagulant can remove a significant amount of the OB, when the optimum dose is exceeded this coagulant loses significantly the capacity to remove OB.

3.1.3 Removal of OB with *Moringa Oleifera*

The percentages of OB removal with *Moringa Oleifera* obtained are shown in Table 3. Again in this case, it can be seen that there is some similar behaviour of the Abs-%OB-Removal data and the TOC-%OB-Removal data.

Table 3. *OB removal with Moringa Oleifera based on absorbance (Abs %OB-Removal) and based on organic load (TOC %OB-Removal).*

	Abs-%OB-Removal						TOC-%OB-Removal			
Moringa (mg/L)	**100**	**200**	**300**	**400**	**500**	**700**	**100**	**200**	**300**	**400**
0.5 h	0.0	3.5	24.1	**24.9**	41.9	43.6	0.0	0.0	18.5	**35.8**
2 h	0.0	14.7	41.3	**48.8**	-	-	0.0	0.0	38.6	**53.8**
4 h	4.8	22.1	48.5	**54.7**	-	-	0.0	0.0	39.1	**61.0**
48 h	-	60.1	81.0	**83.1**	89.2	90.6	25.7	14.2	63.0	**63.9**

The Abs-%OB-Removal shows a removal up to 84.1% of OB using *Moringa Oleifera* at 200 mg/L. Whereas the TOC-%OB-Removal indicate that only 63.9% was removed using the same concentration of moringa at 80 mg/L. It is observed in the table Abs-%OB-Removal (0.5, 2, 4 h) that the greater the concentration of *Moringa Oleifera*, the greater the elimination of optical brightener.

The statistical relationships between of TOC-%OB-Removal and Abs-%OB-Removal from table 1 was determinate by regression analysis. In this case, the data of Abs-%OB-Removal in relation to TOC-%OB-

Removal of the samples treated with moringa at 300 and 400 mg/L have a multiple correlation coefficient of 0.934,

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this means that they have a strong relation. The following relation was established: %OB-Removal-cal = 0.6429*(Abs-%OB-R) + 14.065

Based on this model to calculate the %OB-Removal-Cal data. The relationship between TOC-%OB-Removal and Abs-%OB-Removal response obtained with the previous model is shown at Figure 5.

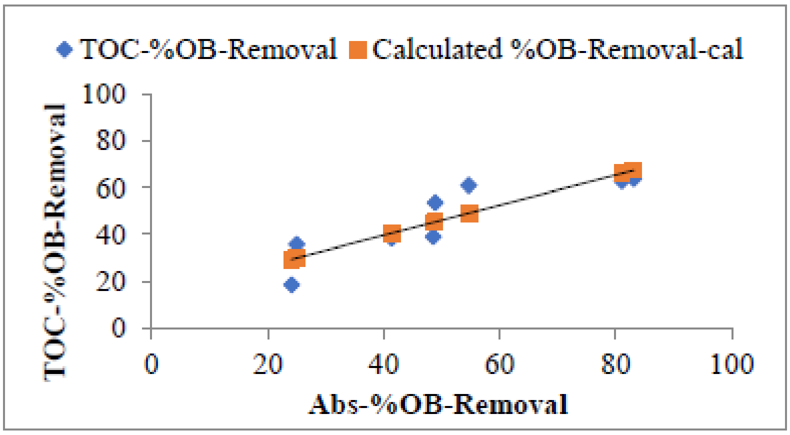

Figure 5. *Fitted line plot displays relationship between TOC-%OB-Removal and Abs-%OB-Removal response and calculated %OB-Removal (%OB-Removal-cal) with Moringa Oleifera.*

The results obtained with the obtained with the %OB-Removal-cal have a direct relation with the TOC-%OB-Removal with standard error of 8.44. The results obtained from %OB-Removal-cal using 300 and 400 mg/L of moringa are shown in Figure 6.

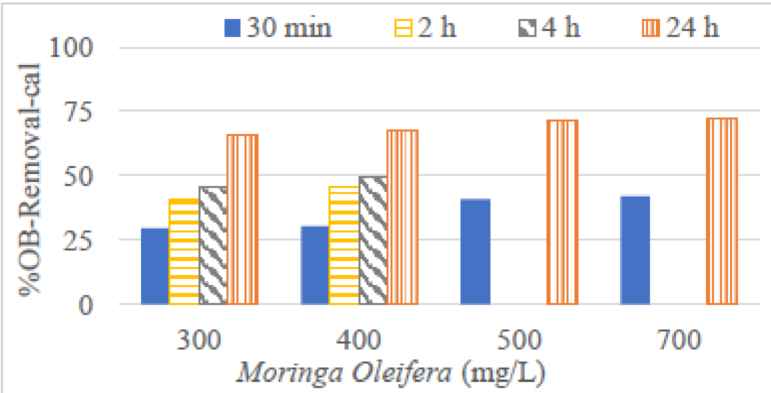

Figure 6. *Removal of OB with Moringa Oleifera (%OB-Removal-cal) Initial OB concentration: 100mg/L when initial OB is 100mg/L.*

Based on the %OB-Removal-cal the maximum removal percentage was 67% with a moringa dose at 400 mg/L. At 24 hours of decanting time the 67% of the OB was removed. It can be highlighted that at 4h with moringa at 400 mg/L was removed the 50% of OB. Tests were also carried out at variable pH (from 3 to 11) using 500 mg / L of Moringa. It was observed that a pH 3 the moringa coagulant did not removed the OB. However, the ability to eliminate up to 70% of BO in water at 24 h was not affected at a pH higher than 4. This agrees with those reported in the bibliography for the elimination of dyes (Vilaseca et al., 2014; López-Grimau et al., 2016).

Since the residual effluents of whitening are usually highly alkaline, the *Moringa Oleifera* is suitable for the treatment of these wastewater.

The initial concentration of OB was increased to 1000 mg/L and treated with *Moringa Oleifera* at 3000, 4000 and 5000 mg/L (Figure 7) in order to maintain the ratio coagulant/OB.

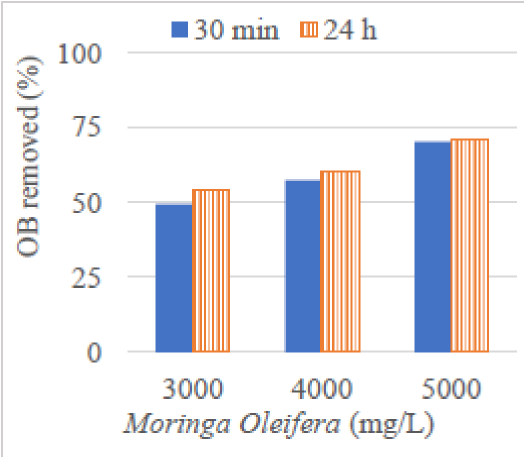

Figure 7. *Removal of OB with Moringa Oleifera (%OB-Removal-cal) when initial OB is 1000 mg/L.*

As might be expected at 24 h a similar percentage removal of OB than the Figure 7 previously shown. It was also observed that the higher concentration of moringa used, the greater removal of OB. In this case, it can be observed that in all test at 30 min of decanting was possible to eliminate the same amount of OB than at 24 h (≤ 5%).

3.2 Treatment and reuse of whitening wastewater

3.2.1 OBs determination of residual whitening water.

Before to the determination of residual OB in the wastewater of the whitening process, the effect of H_2O_2 on OB and on fibre was evaluated. It was assessed that H_2O_2 eliminates between 1 to 5% of OB. On the other hand it was evaluated that H_2O_2 affects the cotton fibre and increases the organic load in the residual water of whitening. The analysis of the wastewater indicated that the organic load in the wastewater, without optical brightener and without hydrogen peroxide, was 69.3 ± 0.3 mg/L of C and with hydrogen peroxide of 270.6 ± 43.4 mg/L of C.

The residual OB on whitening wastewater was evaluated based on the difference in organic load. It was observed that after whitening about 26% ± 4 of OB was lost when the initial solution of OB is 1000 mg/L. Because H_2O_2 has little influence on the OB concentration, it can be approximated to the OB fixed in fibre based on the relation: OB fixed into fibre = (OB on initial solution) – (OB on residual bath)

Higher OB concentration of the initial solution, minimal increase of the OB amount fixed in the fibre. This was observed when initial solutions of OB were 1000, 1200, 1300 and 1400 mg/L. When the initial solution of OB was 1000 and 1400 mg/L it was observed that there was a loss of OB of 234 and 256 mg/L respectively in the residual water of whitening (Figure 8).

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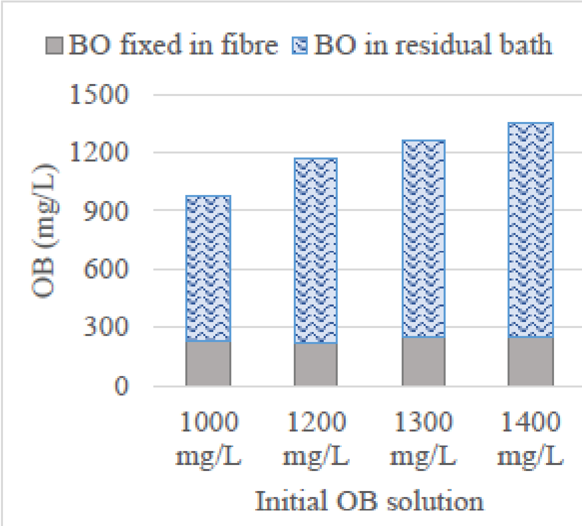

Figure 8. *OB concentration in residual bath after whitenning process and OB fixed in cotton fiber.*

It was observed that 24% of OB was fixed in fibre when the initial OB solution was 1000 mg/L. Most of the OB remains in the residual whitening bath. The higher initial OB concentration, the lower percentage of OB fixed in fibre. This was because the fibre weight was the same in all cases and it was less able to fixing OB, as the fibre was more saturated.

The BO on residual bath was close to 750 mg/L when the initial solution of OB was 1000 mg/L. This result must be highlighted because this wastewater was treated in the next section.

3.2.2 Treatment of residual whitening water with *Moringa Oleifera*

The BO/coagulant ratio determined above is not maintained in the treatment of waste water from the whitenning bath. In section 3.1.2 it was established that more than 50% of an OB was removed when OB solutions of 100 mg/L and 1000 mg/L were treated with *Moringa Oleifera* at 300 mg/L and 3000 mg/L respectively. However, this coagulant/moringa ratio is not maintained to treat residual real wastewater. The concentration of OB in this water was close to 750 mg/L of BO. At a *Moringa Oleifera concentration* equal or lower to 3500 mg /L, it was not effective to remove BO. But with a concentration of *Moringa Oleifera* at 4000 mg/L or higher, it was possible to remove more than 50% of the OB in the residual bath at a decantation time of 30 min (Figure 9).

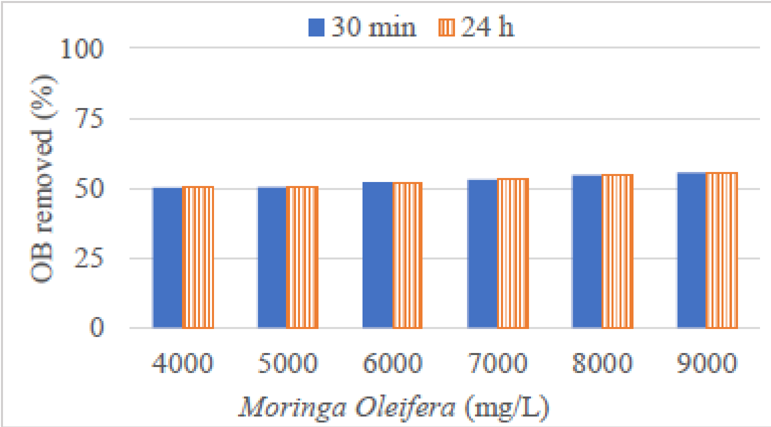

Figure 9. *Percentage of OB removed (%OB-Removal-cal) from whitening residual bath when OB≈ 750 mg/L.*

Higher dose of moringa, minimal increase of the removal of OB. It was possible to remove up to 55% of OB for a decanting time of 30 minutes with a moringa concentration at 9000 mg/L; also when moringa at 4000 mg/L a minimum of 50% of OB was removed for the same decanting time.

It was observed, in Imhoff cone, that when moringa was used at 4000 and 5000 mg/L, a volume of settleable solids of 107 and 110 ml/L was obtained respectively at 30 minutes of decanting and after 24 h of decanting was 53 ml/L in both.

The supernatant of the water treated with moringa at 4000 and 5000 mg/L was collected to make new whitening process with this water. This water contained around an OB concentration of 360 ± 40 mg/L, this mean around 36% of the OB of the initial concentration.

3.2.3 Reuse of residual whitening water with *Moringa Oleifera*

The supernatant of the treated water was used for new whitening processes. The OB concentration of the water treated with moringa was readjusted and also the untreated water was adjusted until reaching the minimum concentration of 1g/L required for the whitening process. It was obtained a solution with 10-15% OB more than that indicated in the recipe. This excess of OB almost does not affect the amount of OB fixed in the fibre.

To evaluate the quality of the whitening process, the Hue and the Whiteness of the fibres were analysed (Figure 10).

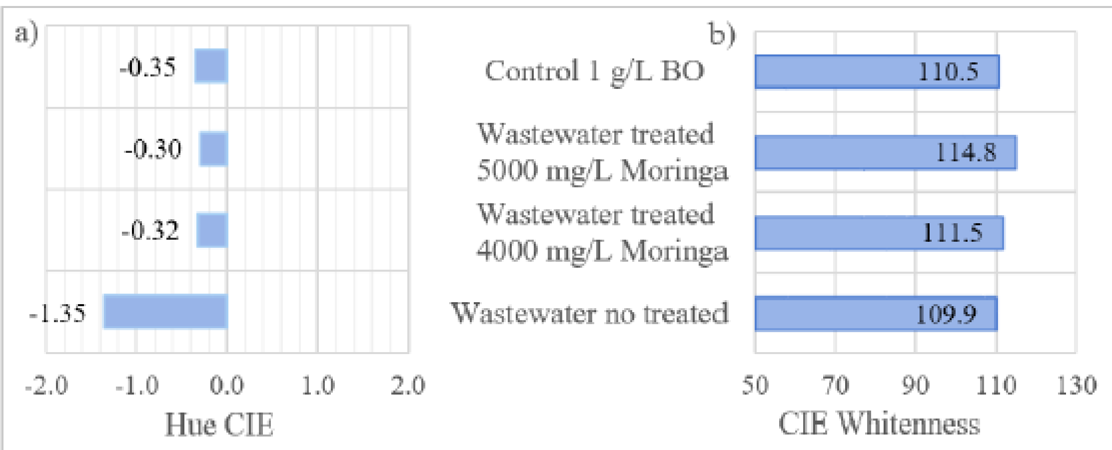

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***Figure 10**. Quality of whitened fibres with reused water, Hue CIE (a) and CIE Whiteness (b).*

The quality of the fibres whitened with treated water was compared to the quality of the control fibres that were whitened with clean water. It is shown, in Figure 10-a, that the Hue in the fibres of the treated water was similar to the value reached with the control sample. A result close to 0 represents the ideal white hue and is considered white fibre when hue values are between -3 and +3 (Riva et al., 2008). Based on this it is concluded that a very good fibre tone was obtained with the treated water.

On the other side, in Figure 10-b, the whiteness obtained by the treated samples was similar to the whiteness obtained with the control sample (110.5). The whiteness in the fibres is inversely proportional to the yellowness (data not shown). Also, a direct relation between whiteness degree and hue is observed, because the higher the CIE whiteness closer to zero was the CIE tone.

It was observed that both, the tone and the whiteness, were slightly higher in the fibres of the treated water than with control fibres. This may be due to factors that can directly affect the whiteness obtained as without BO, H_2O_2 and NaOH; the lack or deficiency of any of these elements in the whitening process results in a lower whiteness degree. It was established previously (Figure 8) that an increase in OB concentration affects very little the OB fixed in fibre. It is assumed that it is due to small deviations of the amount of H_2O_2 and NaOH in the wastewater treated.

4 Conclusions

This study shows that the OB can be removed using coagulation-flocculation, however, these contaminants are difficult to eliminate and none of the coagulants tested achieved a removal greater than 81%. The aluminium sulfate is poorly effective to remove OB from water. While the TIDEC 700, which is a specialized commercial bleaching-coagulant product, is effective to eliminate OB but its performance is poor if the optimum dose is slightly exceeded. At last, the *Moringa Oleifera* coagulant managed to eliminate more than half of the OB of the wastewater, although high doses are needed; an excess in the coagulant dose slightly improves the removal.

Moringa Oleifera coagulant is an alternative to the elimination of OB from textile wastewaters. Particularly in tropical and subtropical regions where this plant can easily be found and it is not possible to purchase specialized commercial coagulant products. In addition, these types of natural coagulants are usually cheap and because they are easy to handle and maintain they can be used by unskilled personnel.

Moringa Oleifera coagulant tends to generate a considerable load of sludge, due to the doses that are necessary to treat the water with OB and because of the particulate material in it. Even though, it has been determined that OB can affect bacterial behaviour, they are not toxic to microorganisms (Gutierrez and Olmo, 2007). The generated sludge is not suitable for agricultural valorization due to its origin (depending on the regulations of each region). To harness the sludge it needs to be stabilized, the OB are eliminated during the sludge stabilization, this is because by aerobic digestion (composting) or by anaerobic digestion (gas production) most of the persistent organic pollutants are removed (I C Consultants Ltd London, 2001).

The wastewater from OB was reused after being treated with *Moringa Oleifera*, obtaining a good whitening quality. The reuse of OB allows the harnessing of auxiliary bleaching products since this residual effluent partially maintains its whitening capacity. It also being prevents these products from reaching the wastewater.

The elimination of OB can be applied in different sectors, where they are used, for example: paper, plastics and detergents industries. This last sector has an important role in the generation and propagation of contaminants to the environment, due to the constant discharge of the domestic wastewater into the sewerage systems.

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Social change beyond consumerism

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Social Innovations for Sustainable Consumption: the social transformation of consumption practices through social currencies

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Abstract

The document "Transforming Our World: The 2030 Agenda for Sustainable Development" established as one of its main objectives "Ensuring sustainable production and consumption patterns." The goals listed are mainly related to the structures and processes that anchor production and consumption practices. The challenge is to promote initiatives that are capable of renewing everyday consumption practices in a way that makes them sustainable, which means meeting human needs while at the same time seeking to respect the limits imposed by the environment. The requires changes in institutional, cultural, political, and market in the way society is structured, which goes beyond technological innovations in industrial processes and products and individual consumer practices. This social transformation can occur from the construction of a more democratic and participatory public sphere that seeks to face the socio-environmental challenges of consumption through social inclusion, in which civil society acts as a protagonist in this process. This action may involve both mobilizations and pressures for the necessary institutional changes to occur as well as in bottom-up movements (Lorek & Spangenberg, 2014) characterized by social innovation initiatives (Backhaus, Genus, Lorek, Vadovics, Wittmayer, 2017) such as the formation of collaborative networks to generate solutions focused on local development, responding social demands through the shared interests and values of and among the communities involved (Seyfang & Smith, 2007). Thus, the question that guided this study was: What is the transformative potential of social innovation initiatives in the promotion of sustainable consumption in relation to dominant institutions in the conventional market? A case study of an exploratory and descriptive nature of the social currency models operated by community banks in Brazil was carried out. Data collection took place through interviews and documentary analysis. The results show that there is a citizen mobilization in the development of more sustainable lifestyles to reduce the environmental impacts of consumption, increase access to consumption and to increase the social welfare of the community where the social currency initiatives implemented by community banks. The use of social currencies is capable of promoting transformations in the socioeconomic relations in the territory towards the improvement of the local living conditions. However, they face challenges inherent to social innovation, such as public policies directed to social finances; legal and cultural recognition of initiatives; and community empowerment. Most of the policy actions developed for sustainable consumption have been more focused on combating the negative consequences of consumption practices involving short-term activities than on understanding, questioning and transforming this practice (Dolan, 2002; Jackson, 2006). Healthy sustainable consumption promotion strategies should focus on attempts to increase human well-being through social structures (Lorek & Fuchs, 2013). Has a direct articulation with social innovation initiatives that discuss alternatives for the growth and development of communities and individuals through emancipation and political participation in their daily dilemmas.

Keywords: Sustainable Consumption, Social Innovation, Social Transformation, Social Currency

1. Introduction

The document "Transforming Our World: The 2030 Agenda for Sustainable Development" established as one of its main objectives "to guarantee sustainable patterns of production and consumption." The goals listed are mainly related to the structures and processes that anchor production and consumption practices. The challenge is to promote initiatives capable of renewing everyday consumption practices in a way that makes them sustainable, which means meeting human needs and at the same time, respecting the limits imposed by the environment. The requires institutional, cultural, political, and market changes in the structuring of society, which goes beyond technological innovations in industrial processes and products and individual consumer practices.

This social transformation can occur from the construction of a more democratic and participatory public sphere that seeks to face the socio-environmental challenges of consumption through social inclusion, in which civil society acts as the protagonist in this process. This action may involve mobilizations and pressures for the necessary institutional changes to occur, as well as bottom-up movements (Lorek & Spangenberg, 2014) characterized by social innovation initiatives (Backhaus, Genus, Lorek, Vadovics, Wittmayer, 2017) such as collaborative networking to generate solutions focused on local development, responding to social demands through shared interests and values among the communities involved (Seyfang & Smith, 2007).

Dealing with social innovation is about finding innovative and acceptable solutions (Moulaert, 2013) to societal challenges, even on a small scale, but which are echoed by more relevant and practical changes and solutions. Recognized as a collaborative process, involving a reconfiguration in social relations, greater participation, and empowerment of individuals, as well as their results-oriented nature, thus, a response to unmet social needs (Klein & Tremblay, 2013; Muller & Tanguy, 2019).

The financial system is one of the primary means of access to consumption, and its development is fundamental to the growth and sustainability of any economy (Lorek & Spangenberg, 2014). Thus, the need for more socially, economically, and environmentally sustainable financial systems has never been more evident than it is today in the midst of a global economic and ecological crisis (Seyfang & Longhurst, 2013). The conventional financial system becomes unsustainable since its central philosophy is exponential economic growth (Michel & Hudon, 2015; Seyfang & Longhurst, 2013) that has physical, ecological, social and human limits, 2009), resulting in environmental degradation, increased poverty and social inequalities among individuals, regions and countries (Miszczuk, 2018).

As an alternative, Microfinance Institutions now incorporate the complex financial system and have in their set of products those linked to solidarity finance with the purpose of democratizing the financial system through the community management of resources composed of three main organizational actors: Solidarity Credit Cooperatives, Solidarity Rotating Funds and Community Development Banks (Rigo & França Filho, 2017).

These organizations seek to minimize the cost of access to credit for low-income populations and promote social inclusion in the relations of production and consumption.

Given these discussions, the Community Development Banks (CDBs) differ from traditional microcredit actions

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because of their organizational and management specificities. CDBs are "solidarity finance practices in support of the people's economies of territories with low human development" (França Filho & Silva Júnior, 2009, p. 103). The primary purpose is to promote the articulation of local actors (producers, consumers and service providers), linked to the solidarity economy movement and concerned with the strengthening of the local economy through the use of endogenous capacities, based on relations of proximity, trust, and solidarity (Rigo & França Filho, 2017). One of its primary forms of operationalization occurs from the use of social currencies.

The introduction of a community bank and social currency in a territory marked by vulnerability and social risk can be considered a social innovation that aims at local development through the provision of financial services offered to its population, organization and strengthening of production and consumption, knowledge, expansion of local capacities and empowerment of the inhabitants of the beneficiary communities (Raposo & de Faria, 2015).

In this context, the insertion of local currency in the local economy constitutes an innovative monetary practice that reconfigures the social and economic process, recovers the agents' ability to influence regional financial flows and social reproduction as a mechanism to circulate resources in the community locations.

Thus, the question that guided this study was: What is the transformative potential of social innovation initiatives based on social currencies in the promotion of sustainable consumption concerning the dominant institutions in the conventional market? That access to credit within a process of financial inclusion by non-bank organizations has been seen as one of the strategies to improve the living conditions of the population of specific territories (Rigo & França Filho, 2017), promoting lifestyles more sustainable (Backhaus, Genus, Lorek, Vadovics, Wittmayer, 2017; Lorek & Spangenberg, 2014). Thus, to answer this problem, an exploratory and descriptive case study of the social currency models operated by Community Development Banks in Brazil was carried out.

In basic terms, this article has five sections. In addition to this introduction, the following section presents the theoretical arguments that link social innovation as a means of promoting sustainable consumption and, subsequently, emphasizing the aspects related to social currencies. In the third section are outlined the methodological procedures adopted, followed by those presented and discussed in the fourth section. Finally, we consider the authors' final considerations.

2. Methods

To meet the objectives of this study, in methodological terms, it is a research with a qualitative approach since it facilitates the study in depth and detail (Patton, 1999), seeks to analyze experiences of individuals or groups, through existing interactions in the context of individuals (Creswell & Creswell, 2017).

Regarding the ends, this research stems from the descriptive and exploratory nature, since it seeks to expose the characteristics of social innovation initiatives based on social currencies in the promotion of sustainable consumption. Exploratory research makes it possible to formulate and define the problem more accurately, to obtain criteria for its approach and flexibility about the methods (Sekaran & Bougie, 2016).

A case study was carried out with the social currency models operated by Community Development Banks in Brazil, for the desire to understand such complex social phenomena (Yin, 2015), participated in the study three CDBs that granted the space for the investigation, totalizing a sample with 10 coordinators that integrated their development and management teams.

As a data collection strategy, data and evidence of different natures were used, namely: bibliographic research, documentary research to collect data and necessary information about the objects of study, such as regiments, norms and procedures, informative and books published by organizations; and field research consolidated by semi-structured interviews with the coordinators. In this sense, the triangulation between the instruments of data collection was carried out to increase the reliability of the research (Yin, 2015), using multi means of data collection.

The script of the interview had questions related to the CDB's role in the process of developing social currencies in the communities, aspects related to the social transformation generated, as well as the challenges faced. The lexical textual analysis incorporated textual content from the interviews using software Interface de R pour les Analyzes Multidimensionnelles de Textes et de Questionnaires (Iramuteq). It is a free program that is anchored in software R, and that allows to make statistical analyzes in corpora textual and tables individuals / words, categorizing data of texts from the evaluation of similarity of vocabularies, in order to subsidize the understanding of the environment of meaning of the words and, therefore, to indicate elements of the representations referring to the object studied (Chaves, Santos, Santosa, & Larocca, 2017).

The interviewees' narrative serves as the basis for the construction of the Descending Hierarchical Classification (DHC) and the analysis of similarities. Each text (n = 10) was classified by variables of interest of the study in a similar structure, based on the previously elaborated questions. The analysis of the corpus from the transcription of the ten semi-structured interviews denoted 9,643 occurrences of words, presented in 926 active forms.

The software generated the classes from the analysis of similarities between vocabulary and multivariate analysis with the variables of interest. This analysis indicated a convergence of the empirical characteristics around four categories: a) Sustainable structure; b) Local development; c) Network articulation; d) Challenges. Before the narratives, the emphasis is on the data of the class of words that characterize the categories of this study after the descriptions, the analysis of similarity.

3. Results and Discussion

According to the Brazilian Network of Community Banks, in Brazil in 2018 there were 103 community banks distributed in 20 states of the Federation. In the Northeast, in particular, where development has not occurred impartially compared to other regions of the country, there are 52 community banks, mostly concentrated in the state of Ceará, with 36 banks, the birthplace of the first experience, Banco Palmas, founded in Fortaleza in 1998.

Also, there has been a more significant social participation in the debates and demands in national plenaries of solidarity economy, resulting in government policies that treat solidarity finance as alternative financing instruments for socio-economic development (Raposo & de Faria, 2015).

The CDBs are a phenomenon under construction, and the discussion of these experiences in the country are fundamental for understanding the meaning of its development. Although they follow the methodology of Banco Palmas, a pioneer, and national and international reference, communities have peculiarities, different histories, their knowledge, and learning, so it is crucial to understand the various strategies and methodologies that CDBs and social currencies can assume in different contexts and regions of the country (Raposo & de Faria, 2015).Within the study, three community banks were investigated, through their development and management coordinators,

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presented below.

3.1 CDBs initiatives that operate in Brazil

Banco Palmas is a typical case about social innovation and local development of a poor community - Conjunto Palmeiras, located on the outskirts of Fortaleza-CE, Brazil. It is a collective and socially innovative initiative whose solutions, in response to the socioeconomic challenges of the residents, have led to profound local and social changes in the community. This initiative is a social innovation with collective effects, where the social dimension remains fundamental, and the economic impact is seen, through the creation of an accessible bank in 1998, as well as the granting of microcredit low-income population.

Reflecting on the situation in which they lived, and the expectations of urgent changes, it became evident the need to strengthen the economy of the neighborhood and improve the lives of all. In this way, the people built most of their economic relations out of the community, weakening the local economy. A project began to be thought and developed collectively and received the name of Banco Palmas, inaugurated in January of 1998.

Thus, the Palmas Bank emerged as a result of the Association of Residents of the Palmeiras Set and the strengthening of a poor community that fights for decent living conditions. Banco Palmas Project was created to guarantee microcredits for local production and consumption at low-interest rates, without requiring registration, proof of income, or guarantor. More than a formal register for granting credit, it required a knowledge of the life of the borrower's person in the community. In this way, it strengthened the local economy, and the residents began to make their purchases inside the neighborhood, stimulating the internal circulation of wealth.

Currently, the Bank works with several fronts, from community activities, associations and demands, providing banking services, providing small loans, fostering local entrepreneurship, training activities and training to support the creation and coordination of new community banks with the dissemination of this methodology developed by the Palmas Institute.

The Banco Jardim Botânico, located in the São Rafael community in João Pessoa, was the result of a partnership between the community and the incubators of NCUBES / UFPB and ITES / UFBA. The São Rafael community is considered an area of risk and economic and social vulnerability. It has an active community organization, consolidated over the years with the presence and support of various organizations and public policies for social inclusion in the neighborhood. Among these institutions, the Popular Center for Culture and Communication stands out as a great leader in the actions and projects carried out in the field of solidarity economy, both in partnership with the public power and with civil society institutions.

Taking into account the organizational history of the community and its involvement with the solidarity economy, INCUBES decided to expose the idea of the community bank with social currency as a new local development strategy. The bank was then supported, through a public announcement, by the National Secretary of Solidarity Economy of the Ministry of Labor and Employment for the implementation of community development banks in Brazil and the strengthening of the Brazilian network of community banks.

The decision by the São Rafael Community was motivated by the follow-up that had already been carried out in the neighborhood by INCUBES, and the perception that there were favorable conditions for the development of a Community Development Bank, such as active community organization; economic solidarity initiatives in progress; profile of local leadership and other projects and institutional support in the territory.

In the year 2012, the community launched social currency Orquídea. At Banco Jardim Botânico, the social currency Orquídea stimulates credit concessions for consumption. It is accepted within the community by merchants registered by the bank, with the idea that the resource rotates within the community.

Banco Popular de Maricá is an initiative created by the municipal public authority and not the population of the municipality. Established in January 2014, the Banco Popular de Maricá is located in the city of Maricá / RJ and is a singular experience as a methodology of community banks, recognized as a municipal public policy.

The purpose of this government alternative is to establish partnerships with public or private entities for the operation of the Community Bank of Maricá, as well as to create public solidarity economy centers and public incubators of joint ventures, fair commercialization centers, festivals, solidarity shops, and other decent trade instruments.

Mumbuca (name of the river that cuts the municipality) is passed on and circulated as a virtual social currency via magnetic card. Small registered stores receive machines that accept the magnetic card. The beneficiary families will be encouraged by the bank to create cooperatives and productive groups and intend to provide credit to cooperatives, associations, artisans, small merchants, and fishers, as well as products such as insurance and training courses.

It is a differentiated case regarding the initiative of creating the bank, the way it is structured while maintaining the inclusion character that the bank provides and mobilizing the community for the debate around the project — development of the territory.

3.2 Processes of social innovation in community banks through social currencies

The analysis of the corpus by Iramuteq allowed the accomplishment of the Correspondence Factor Analysis (CFA) in the frequency counting, and the Qui2 correlation values of each word in the corpus, and all variables analyzed and the index used was Qui2. The Iramuteq program recognized the separation of the corpus in 264 texts or comments. The DHC retained 207 texts, 78.40% of the total, and divided the corpus into four categories, as shown in Figure 1.

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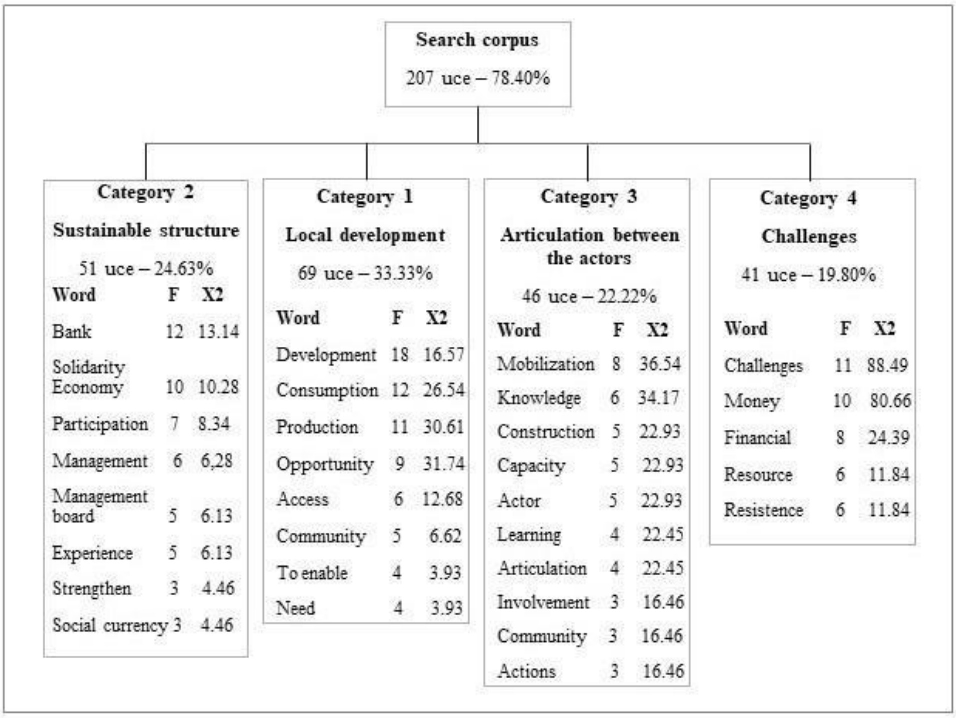

Figure 1. *Dendogram of classes based on interviews*

The Sustainable structure category (Category 2) accounted for 24.63% of the total comments. This class presents elements related to the performance of community banks as financial, solidarity, network, community and community services, aimed at reorganizing local finances, in the perspective of solidarity economy.

According to the interviewees, the CDBs have an associative and community nature because the ownership of each bank is from a local social organization, through a residents association, or a settlement, a group of women among other options - that work in a network. The three cases analyzed resemble the driving style. They work by investing credit for the local production of necessities and also for the consumption of these local producers. That's why consumer credit is in social currency.

Each community bank has its social currency, which circulates in a given geographical area, generating local commerce, causing wealth to advertise in its neighborhood and people not dependent on the external market, but to buy and produce locally.

The reference to the performance of the Banco Palmas was a great inspiration to introduce a social currency in the projects. The methodology adopted by Banco Palmas identifies a process of collaboration and networking between producers, local businesses, and the population, thus stimulating collaboration between companies and consumers. The results in the implementation of a local production system. It takes into account social innovation as a new response and towards the satisfaction of a social need.

Strategies are discussed to encourage local entrepreneurship, from the skills that people have and from what the municipality offers, to increase the flow of resources in the locality, as well as generate opportunities to improve the living conditions of the community, without, for they needed to leave their place.

For insertion in the communities, the clients are encouraged to have discounts of up to 20%. It strengthens demand, and local prices become more competitive. Respondents say that local merchants and service producers lower costs as it compensates for the large-scale gain. In this context, the local social currency must operate through payment restricted to the particular community, which through a commercial pact in granting absolute shopping exclusiveness in the neighborhood, seeks to avoid leakage of purchasing power to other localities.

Another emphasis pointed out by the interviewees is that community banks also incorporate non-financial mechanisms, which constitute a reconfiguration of economic and social relations. Beyond the provision of services, the activities of the Community Bank presuppose and require a new form of management, sharing of decision-making power, and participation of the local population in actions that cover the various sectors of society.

In this process, social agents perceive their importance in the development of the community and see themselves as economic and change-generating subjects. Thus, they acquire critical and discursive capacity, think, and discuss their reality. The participatory process allows the appropriation of the Community Bank instrument and can lead to more effective methods of community emancipation.

The community bank values people and mobilizes community organizations from the services it offers: current social currency, solidarity credit for production and consumption without interest in social currency; or low interest in real, widespread credit card solidarity, opening and deposit account, loose or magnetic card (available in some experiments), receipt of bonds, payments, and benefits. The services offered to promote the inclusion of a significant group of the population that does not have access to traditional banking services and remains financially excluded.

The category Local development (Category 1), with the highest amount of comments (33.33%), brings references to the introduction of a community bank and social currency in territories marked by vulnerability and social risk. They are considered a social innovation that aims at local development through the provision of financial services offered to its population, organization, and strengthening of production and consumption, knowledge, expansion of local capacities and empowerment of the inhabitants of the communities.

The social currency has local circulation, and it is an innovative monetary practice that reshapes the social and economic process, recovers the capacity of agents to influence the flows of the local economy and social reproduction as a mechanism to circulate local resources in the community.

One of the interviewees affirms that "the territory where the social currencies and their marketing circuits are developed is decisive for the success of the initiative" [Actor_04]. The social currency has spatial and geographic restricted validity, having a fundamental principle the stimulus to the production and circulation of local riches. Unlike traditional forms of payment, they do not serve as a means of accumulation, but by moving within spatial constraints, they promote the activation of local productive capacities.

The cases investigated present an emancipatory and participatory perspective of local development, pointing out concerns with the social and spatial peculiarities of the communities. In this way, they characterize themselves as a process of dynamization of their potentialities, based on the mobilization of resources or endogenous conditions of the territories and initiative of local actors through the active protagonist of the popular participation to transform their social reality.

It is worth noting the case of the Orquídea social currency, which receives support from the University Incubator,

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who accompany these processes, "contribute to the mobilization of resources, form new technical and political frameworks for acting in solidarity-based local development processes, and learn in this process through the construction of new knowledge" [Actor_06]. They are actions of university extension that articulate the community action aiming at the resolution of concrete social problems, also pointing to a new form of relation university and society.

The CDBs work their actions for territorial development, strengthen and provide freedoms that sustainably develop the territory and value the individual, enabling conditions to build their capabilities and requirements to social transformation.

They also foster another economic logic of development by promoting actions that expand the capacities needed for the territory to develop. The local, territorial development approach can be considered adequate when it can identify and mobilize social actors, economic resources, and cultural aspects, which must be harnessed and developed locally, increasing social capital.

One of the identified dimensions concerns the articulation between actors (Category 3), with 22.22% of the total comments. Its elements are mainly related to the position that for the development of the social currency, there was a need for a network of collaboration, through a plural economy.

When asked the interviewees about the main actors involved in the process, they mentioned the involvement of several partners, such as national and international universities, NGOs, Federal Government, financial institutions, City Hall, and neighborhood associations.

The collective action of the community is a propelling factor for the effectuation of social innovation. It is the voluntary mobilization of social actors for a common benefit, as verified in the three cases studied. In the interviewees' statements, it was possible to check the strong relationship of social innovation with local leaders and the community, both in terms of its conception and in its development and implementation.

The participation of local communities in the design and development of the community banks in question was encouraged. This methodology allows verifying in loco the involvement of the community leaders in the decisions tied to the CDB.

The social currencies visualized in this study go beyond a new business model or the development of new technology, but a change in social relations, empowerment, inclusion, and participation of society. Lack of credit and non-marketing of local products in the neighborhood were aggravating factors for the non-economic development of the community, thus fostering innovative initiatives that would bring about the socio-economic transformation of the population, thus contributing to local and regional development.

It is a priority in these actions of solidarity economy, the formation of collaborative networks that integrate consumer groups, producers and service providers for the practice of solidarity finance, ethical consumption, production fair trade.

The development of the capacities of the local agents reflects in the resolution of social problems through public policies as a condition for the construction of a strategy of regional development with integration, participation, and partnerships. Encouraging participation involves the local community in designing and implementing local development programs by providing information and engaging in community planning, an essential aspect of strengthening a CDB.

The CDB is a space of experimentation and learning that is effective in the development of its actions, in the collective construction, in the overcoming of challenges and in the practices that change the individual's perception of his role as citizen, being able to modify his vision of the community, their organizations and prospects for the future.

Category 4, called Challenges, represents 20.38% of the comments retained in the analysis. Its content covers aspects of the challenges related to the difficulties associated with lack of legal recognition, access to funding, lack of constant involvement among the actors involved, and skills and training.

The barriers faced arising in the very conception of social currency. In regulation, the social currency is only contractual, and there is no link with the Central Bank of Brazil. The cases reported that, in the initial stage of the implementation of the social currency, several obstacles followed with the Central Bank of Brazil. Among them, an order from the central bank to close Banco Palmas twice, including opening criminal proceedings.

In this case, the formal aspects of the institutional environment, which until then regulated such activities, consisted of inhibiting factors for the social currency, not only in the lack of access to financial services but above all in the formal inhibition of such initiatives.

Currently, there are specific legislation and public policies for this service, with the creation of the National Bank of Communities. It constitutes a regulatory apparatus that allows the microcredit activity to operate safely and lawfully. Nevertheless, according to one interviewee from Banco Palmas, there are still several barriers to access to cheaper resources and more specific regulations for the sector.

There is also the challenge of constant mobilization of social actors involved in the community. In the beginning, there was the participation of a considerable portion of the population throughout the construction process. This involvement remained until a few years after the inauguration of the banks, through active involvement in the representations of the Councils, in the claims and suggestions for the improvement of the services provided by the bank. However, the interviewees affirm that participation diminishes with the consolidation of the social currency. In this sense, one of the present challenges is to make people actively participate in the discussion and management spaces.

The lack of training and skills development of professionals working with social initiatives leads to a deficiency in the performance of these professionals. The nature of social currencies, as an instrument of solidarity economy, requires skills to connect to various sectors, domains, and political interests. Competency gaps link to lack of knowledge of legal aspects, management, fundraising, and leadership skills.

These barriers face the lack of education necessary to promote active citizenship, awareness of the role of empowerment, mutual learning, and participation in the reform of society. How the actors interact and coordinate the development of a social innovation generates a potential in the individuals, through a process of learning to acquire knowledge, change of representations, new learning and a system of cooperation.

The similarity analysis, another tool provided by Iramuteq, synthesizes the highlighted categories with an emphasis on the terms "Local development", "Sustainable structure", "Articulation between the actors" and "Challengers". The analysis organizes the interviewees' overview of their perception of social currency as a social innovation for the transformation of new consumer practices, as shown in Figure 2.

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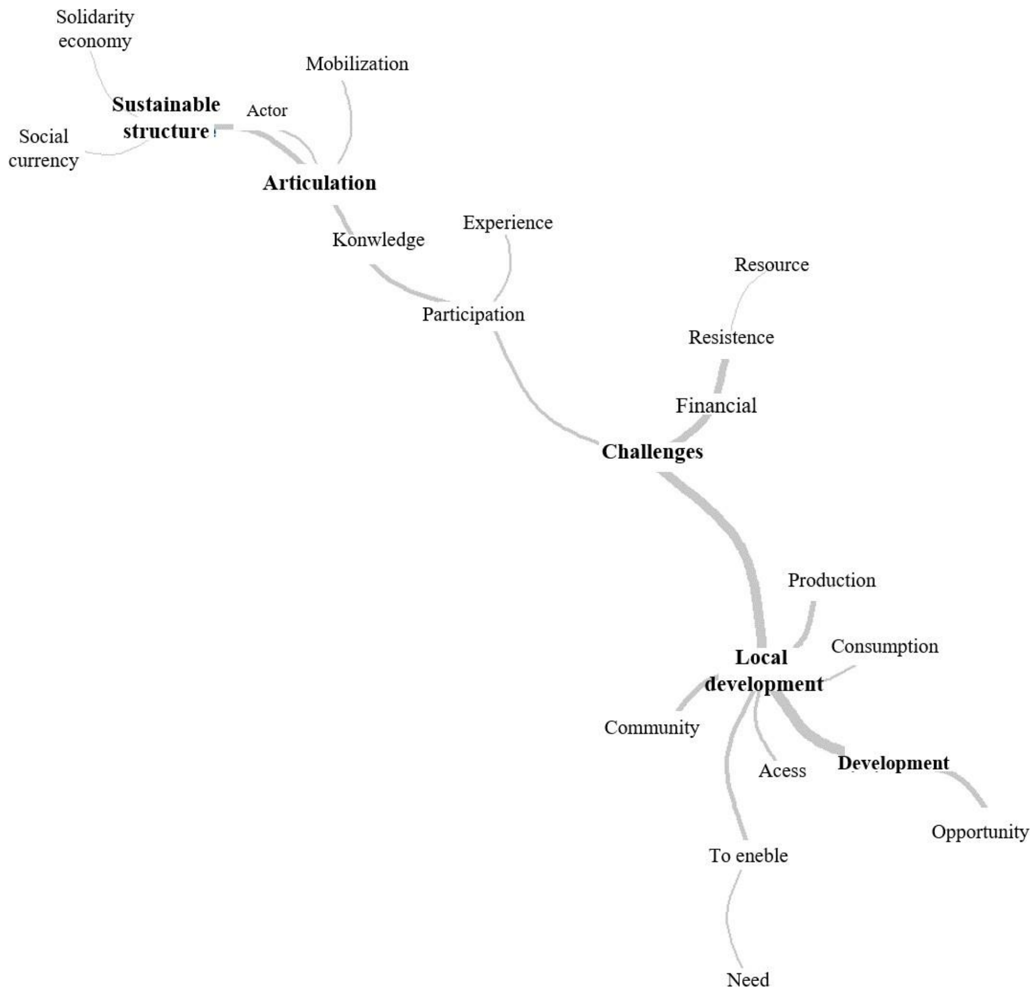

***Figure 2**. The similarity of identified categories.*

In this way, they are consonant to the understanding that the community banks are social innovations linked to the territorial development that uses the social currency as an instrument of articulation of the sustainable production and consumption for the strengthening of a local economy.

The actions developed do not only value the economic aspects but the social interaction and collective learning that can modify the reality of the community and the overcoming of the challenges from a reflexive action on the part of those involved in the development processes. Local actors act in an integrated way in the management of a sustainable structure that aims at community development, strengthening local communities, and training leaders to conduct their development projects.

4. Conclusions

This article aimed to analyze the transformative potential of social innovation initiatives based on social currencies in the promotion of sustainable consumption concerning dominant institutions in the conventional market. The results show that, despite following the methodology of Banco Palmas, the other two communities investigated have peculiarities, management structure, knowledge, and own learning. In this way, it is crucial to understand the different strategies and methodologies that CDBs and social currencies can assume in different contexts.

The development promoted by the CDB articulates the social, economic, political and cultural, insofar as it gives greater consistency to the actions of community associations, encourages the organization of local economic activities, supports the production, commercialization and consumption initiatives in the neighborhood , carries out new partnerships and projects with government agencies, develops capacity building and training activities for its residents, among many other actions and events that become part of the daily life of the community.

In this context, there is a citizen mobilization in the development of more sustainable lifestyles to reduce the environmental impacts of consumption, increase access to consumption and to increase the social well-being of the community where the bank's Community level implements social currency initiatives. The use of social currencies is capable of promoting changes in socio-economic relations in the territory for the improvement of local living conditions. However, they face challenges inherent in social innovation, such as public policies focused on social finance; legal and cultural recognition of initiatives; and community empowerment.

Most policy actions developed for sustainable consumption have focused more on combating the negative consequences of consumption practices involving short-term activities than on understanding, questioning and transforming this practice (Dolan, 2002; Jackson, 2006). Effective strategies to promote sustainable consumption should focus on attempts to increase human well-being through social structures (Lorek & Fuchs, 2013). It has a direct articulation with social innovation initiatives that discuss alternatives for the growth and development of communities and individuals through emancipation and political participation in their daily dilemmas.

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Repair in society policy and product design

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Uncovering the re-use potential in Swedish recycling centres

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Abstract

This contribution investigates the potential of re-using waste that have been submitted to recycling centres in Sweden. Following the waste hierarchy principle, waste prevention and re-use are considered better management options than recycling. However, prevention and re-use activities are difficult to operationalise and measure, without a monitoring framework in place. Recycling centres receive a wide variety of materials for recycling, of which a portion could be re-used instead. The aim is to identify what product groups can be re-used, how high the share of these products are in the recycling centres, and under what conditions re-use is feasible. A literature review of similar studies, site visits at recycling centres, and semi-structured interviews with relevant stakeholders were used to analyse the potential for re-use in private recycling centres in Sweden. The most suitable product groups for re-use identified are building materials, furniture and electrical equipment (mainly white goods), as other material types are handled by public or charity organisations (e.g. textiles). There is significant potential for increasing their re-use operations in recycling centres, but in order to be economically profitable it is important to identify the most suitable material fractions (or product groups) and engage in strategic partnerships that will allow more effective organisation of re-use processes.

Keywords: Waste Hierarchy, Re-Use, Recycling Centre, Circular Economy

1. Introduction

Waste management in the European Union (EU) is defined in the EU Waste Framework Directive (2008/98/EC), which outlines the rules and conditions under which waste management operations and planning are taking place in EU Member States. It is complemented with a number of Directives setting the rules of managing separate waste streams (e.g. packaging waste, electronic waste etc.). The central principle of EU waste management, as it is expressed in Article 4 of the Waste Framework Directive, is the so-called "waste hierarchy". The waste hierarchy addresses the prioritisation of waste management options according to environmental and resource efficiency aspects. According to this hierarchy, waste management operations with negative environmental impacts are considered undesirable and should progressively be limited, substituted by waste operations that are considered more resource efficient and environmentally sound (EC, 2008).

The waste hierarchy includes the following waste management operations: (a) waste prevention; (b) re-use and preparation for re-use; (c) material and biological recycling; (d) energy recovery from waste; and (e) disposal to controlled or uncontrolled landfills, land or water. It is worth noting that although the hierarchy is addressing waste management, step (a) and partially step (b) of the hierarchy deal mainly with non-waste. Waste that is prevented is waste not generated, and re-use of a product means that the product did not become waste in the first place. However, step (b) might indicate that a product first became waste and then brought back to a suitable condition for re-use.
The term *"re-use"* is defined in the Waste Framework Directive as *'any operation by which products or components that are not waste are used again for the same purpose for which they were conceived.'* (EC, 2008, Art. 3). Product repair, refurbishment, and remanufacturing are all considered to be re-use operations (Ijomah and Danis 2012), and are often environmentally preferable to material recycling and manufacturing of new products as they save material resources and energy, reduce greenhouse gas emissions, and lead to safer handling of potential toxic substances in products (Sundin and Lee 2012).

Waste management in the EU has moved steadily upwards the waste hierarchy, prioritising options considered as best alternatives. Indeed, the recycling share of municipal solid waste has increased from 30% in 2004 to nearly 44% in 2014 (EEA, 2017). However, there is an apparent lack of information concerning the performance and progress of Member States in re-use operations. Considering that re-use is an immediate step up from recycling in the waste hierarchy, it would be evident for municipalities following waste legislation (and for their subcontracted private enterprises) to strive to get to the re-use stage of the waste hierarchy.

In Sweden, more than half of all municipal recycling centres include the possibility to receive materials for re- use, such as clothes and furniture, often in collaboration with charity organisations. There are also recycling centres with recycling parks that have extended operations, such as repairs and sales of second hand goods. The volume of waste submitted to the municipal recycling centres in the last years is steadily increasing, and so are the possibilities for re-use of a variety of products and materials (Avfall Sverige, 2018). Moreover, in addition to the municipal recycling centres, private enterprises have capabilities of collecting a variety of waste from municipal or private actors within their own facilities, with a good potential for re-use (STENA, 2016).

In this contribution, we are investigating the potential of re-use and the possibility of ascending the waste hierarchy in

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commercial recycling centres in Sweden. Similar to previous studies that have analysed the re-use potential in municipal recycling centres (Ljunggren Söderman et al., 2011; Hultén et al., 2018a; Hultén et al., 2018b), for this study we conducted a qualitative analysis of the different waste streams treated in two sorting facilities of the largest recycling operator in Sweden. The analysis aimed at assessing the type of waste streams and the quality of waste, and to examine if the waste could have been re-used instead of recycled. In this study, we did not consider the types of material such as plastic, metal or wood, but product groups such as furniture, building components, etc. Analysis of re-use potential at product level allows better understanding of where and when re-use is feasible, which can facilitate new business models for re-use involving the recycling centres.

In the following sections, we present the main characteristics of re-use concerning environmental, economic and social aspects, as well as legal implications of re-use. Then, the methodological approach of this contribution is presented, followed by the integrated results and discussion. Finally, this contribution ends with presenting the main conclusions and future research opportunities.

2. Characteristics of re-use

This section outlines the sustainability characteristics of re-using end-of-life (EOL) products and presents the associated legal and organisational implications of re-use. Additionally, previous studies on Swedish municipal re-use centres are presented, highlighting important conditions of re-use relevant to the present study.

2.1 Environmental benefits of re-use

Waste prevention and re-use is generally considered a better environmental option than other treatments of waste. For instance, preventing the generation of one kilogramme of textile waste can potentially reduce carbon dioxide (CO_2) emissions by 15 kg, while the amount of reduced emissions is 8 kg CO_2 if that one kg of textiles is re-used and approximately 0-3 kg emission reduction if textile waste is recycled (Avfall Sverige, 2015). A deviation from this general principle can occur when products have been designed to be much more energy-efficient in their use phase in the product's life-cycle. Generally, products that have a large energy consumption after manufacture are not as favourable to re-use (Gutowski et al, 2011). Another example of products that are less suitable for re-use are products that contain hazardous substances which, when re-used, persist in the product stock in use and are not phased out (Eriksen et al., 2018).

A previous study by Ljunggren Söderman et al. (2011) measured environmental impacts of re-use by life cycle assessment (LCA) methodology, using as case study the recycling centre Alelyckan situated in Gothenburg, Sweden. Contrary to a "traditional" recycling centre, where received waste are destined solely for recycling, the Alelyckan recycling centre offers the opportunity to collect waste for re-use before they reach the recycling bins. In 2010, the recycling centre prevented 358 tonnes of waste, which corresponds to 5.6 per cent of the total weighted waste received at the centre (Ljunggren Söderman et al., 2011). Figure 1 shows the amount of waste collected for re-use (tonnes) and the amounts that were actually re-used in each product category. The figure shows that the product groups with the largest amount re-used were textiles and metal products. Books were also common but these proved difficult to re-use. Furthermore, the figure shows that all wood construction products collected were eventually re-used.

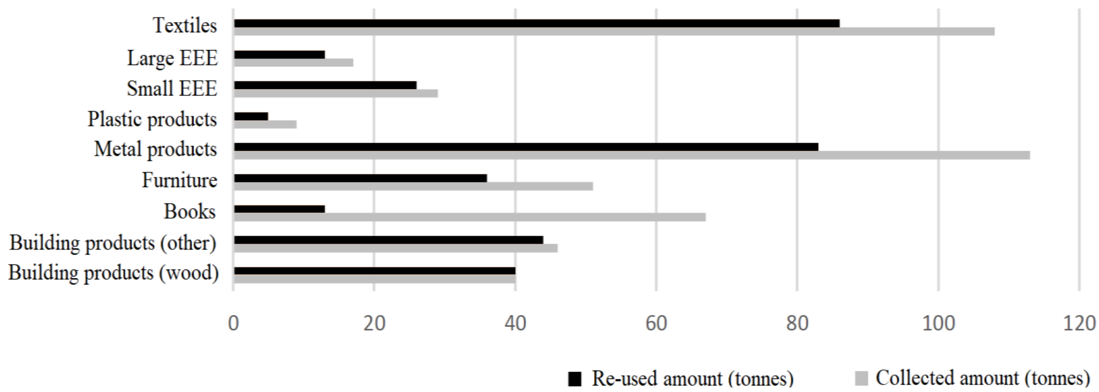

***Figure 1**. Collected and re-used amounts of waste at Alelyckan recycling centre in 2010 (Ljunggren Söderman et al., 2011). Note: EEE stands for Electric and Electronic Equipment.*

The study investigated, among other things, the environmental impacts (in the form of greenhouse gas emissions, acidification and eutrophication) due to avoiding new production and waste transport, and the increase or decrease in energy recovery; in Sweden, most waste that is not re-used, composted or recycled is burned in municipal incinerators connected to district heating systems. The LCA calculations for the 358 tonnes of waste that could be re-used confirm that the greatest environmental benefit is due to replacement of new production. The carbon dioxide savings that could be made in one year by the introduction of Alelyckan compared to a conventional recycling centre were 1,300 tonnes of carbon dioxide equivalents (Ljunggren Söderman et al., 2011). This amount is equal to the total emissions of 120 Swedes over one year, including private and public consumption in and outside Sweden, i.e. about 11 tonnes per person per year (SEPA, 2018a). It is primarily textiles and small electric and electronic equipment (EEE) that have a major impact on avoided greenhouse gas emissions during re-use. For textiles, the result is largely influenced by the fact that large amounts of textiles were collected at the recycling centre, while small EEE have a greater environmental impact per tonne collected (Ljunggren Söderman et al., 2011).

The study also shows that in 2010 the recycling centre prevented emissions of substances with acidifying and eutrophication effect by 10 and 1.5 tonnes respectively, which is in the order of the annual emission of 400 Swedes. In conclusion, the study notes that if all recycling centres in Sweden were rebuilt with a re-use concept similar to Alelyckan, then about 80,000 tonnes of waste could be prevented annually (Ljunggren Söderman et al., 2011), which is as much waste generated as in a medium-sized Swedish city, taking into account that a Swede generates on average 473 kg of household waste per year (Avfall Sverige, 2018).

2.2 Economic aspects of re-use

The economics of a business, whether private, non-profit or public, plays a central role in determining its feasibility and long term sustainability. Unlike conventional recycling centres, the operating cost of a centre with a re-use focus is higher. Personnel costs increase as more staff is required to sort the incoming waste, inform visitors, and label waste that has been prepared for re-use. Higher premises costs arise as a result of an additional sorting station, storage facilities and more sorting containers (WSP, 2012). There are various alternatives to cover the increased costs. One

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example is to regulate the municipal waste tariff. This is possible since the preparation of waste for re-use can be classified as a recycling activity. There is therefore no legal obstacle to using income from the waste tariff to finance such activities (Avfall Sverige, 2014). In addition, it is commonly observed that re-use organisations in several EU countries have been receiving state support, directly or indirectly, to maintain their operations (Zajko & Hojnik, 2014).

Furthermore, the waste collected for re-use has an economic value as a product. It can therefore be assumed that re-use of products can also have higher economic benefits, in contrast to recycling (Avfall Sverige, 2015). The waste streams entering a recycling centre can be quite heterogeneous and can also vary depending on the season. This means that even the commercial value of the waste may vary, thus also the interest from external actors. The types of products also affect the value of the waste. Products with a high commercial value will most probably not be left at a recycling centre (although this is not always the case). Products that end up in a recycling centre are most often things that households do not consider sufficiently valuable to divert in a second-hand outlet, however, there is still some residual value in them, which can be harnessed if the recycling centre is connected to repair services (Hultén et al., 2018a).

2.3 Social aspects of re-use

The social effects of re-use concern mainly increased employment and inclusiveness. Traditionally, non-profit second-hand businesses provide a workplace opportunity for many people who find it difficult to enter the labour market in any other way. A study conducted to investigate social benefits with second-hand activities (Jannesson & Nilsson, 2014) concluded that a large proportion (74%) of people employed in a second-hand business through an internship, employment with subsidies or work training experience increased meaningfulness, reduced stress, increased participation in society and improved social relations. There are also social effects for customers who buy second-hand products. A growing secondary market would have a positive effect on households as they gain greater access to affordable products. Other positive effects for the consumer may be the feeling of acting environmentally conscious or that the money from purchasing second-hand goes for a charitable purpose.

2.4 Legal aspects of re-use

An important parameter when designing a re-use centre is the embedded legal framework concerning the management of waste and associated re-use activities. In Sweden, according to the Environmental Code (SFS 1998: 808), each municipality is responsible for disposing or recycling household waste. Part of the municipal responsibility is therefore to establish recycling centres where citizens can leave waste that are not collected from households. When a product has been submitted to a recycling centre, this is transferred to the municipality's ownership. The right of ownership means that the municipality has the exclusive right to decide on how the waste is to be treated, taking into account national guidelines such as the waste hierarchy. (Avfall Sverige, 2014).

For businesses that handle products submitted with the explicit purpose of being re-used, and thus will not be classified as waste, a waste management permit does not have to be applied, according to the Environmental Assessment Ordinance (MPF) (SEPA, 2017).

For re-use to be possible, in some cases it is required that the submitted waste is in some way processed or prepared for re-use. This may, for example, involve checking, repairing or cleaning. In the most recent amendment of the Environmental Assessment Ordinance (MPF) (SFS 2013: 251), a point of appeal was added, namely para. 47 "Preparation for re-use" with business code 90.29. This facilitates the operations of businesses that work with preparation for re-use, as such activities are classified obligatory for notification and therefore do not have to undergo an authorization process, but only a notification to the municipality is required (SEPA, 2017).

An important aspect to take into account in municipal sales of recycled goods is the Competition Act (SFS 2008: 579). This is because the state, county council and municipality must not conduct a sales activity that can distort or impede private competition. This may be the case if waste at a recycling centre is pre-treated and sold under municipal auspices. Other recycling operators do not have the same opportunity and can be disadvantaged. One possible interpretation, however, is that other actors are not able to run collection, sorting and preparation for re-use to the extent required to fulfil the municipal responsibility, and therefore there is no competitive advantage for the municipality. Regardless, the municipalities must take into account the Local Government Act (SFS 1991: 900) which states that a municipality must not conduct activities with a profit interest and that all activities within municipal operations must have a public interest purpose (Avfall Sverige, 2014).

To circumvent potential distortion in competition, and legally uncertain practices, it is recommended that municipalities cooperate with private actors. The contractual form between a municipality and private actors affects the legal framework of the collaboration. A dividing line is who pays and for what. Hultén et al. (2018a)

provide several examples to illustrate such inconsistencies. For instance, if a municipality gives collected products to private operators, this can be seen as unauthorized individual support for traders. Transparent selection process among players is needed and at least local rent or similar should be paid by the private parties. In another example, a municipality could pay private actors to receive collected products, and this could be considered as the provision of service to the municipality and in that case formal public procurement processes must be applied. Finally, a municipality could sell collected products to private operators. Procurement or selection among relevant actors is not required formally if sales are made at market prices. On the other hand, if the sale is made by renting an area or at a discounted price, it may be an unauthorized individual support for the trader and the selection process becomes necessary.

2.5 Re-use potential in municipal recycling centres in Sweden

To identify the potential of re-use in a recycling centre, it is important to identify the type of products that are submitted and what condition they are in. A recent study conducted in two municipal recycling centres in Sweden (Norra Hamnen in Malmö and in Örkelljunga) quantified the received waste for re-use and assessed its quality and re-use potential (Hultén et al., 2018a; Hultén et al., 2018b). In total, 15.5 tonnes of waste was examined through composition analysis, and the re-use potential of nearly 17,000 products was assessed.

About a quarter of the waste examined was considered commercially or functionally re-usable (Figure 2). A very small percentage was judged to be commercially re-usable after repair (3%), but many of the products that were

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considered to have a resale value in their existing condition would have a higher value if they were also repaired. Among all items deemed re-usable, a further distinction was made between commercially re-usable and functionally re-usable products. The latter, although retain functional capability (i.e. product can be used for its intended purpose), they have negligible economic value and are not commercially viable. That waste category constituted five percent by weight, including products such as used socks and plastic pots. More than two-thirds of the waste that was investigated consisted of other waste types such as packaging and garden waste or products in poor condition that could not been re-used.

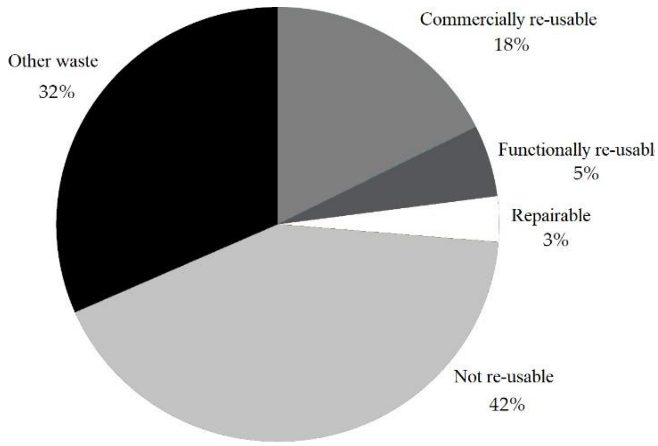

Figure 2. *Results of the composition analysis of waste at two recycling centres (Norra Hamnen in Malmö and Örkelljunga), showing re-use potential expressed by weight of received waste (Hultén et al., 2018a).*

The largest amounts of commercially re-usable products did not belong to the more traditional product groups handled by charity organizations, as for instance clothes. Building products, furniture, pallets and tools were commonly the ones that were identified with a high re-use potential. Repair work was not judged to be able to increase re-usable amounts to any notable extent, even if it was performed with no cost. Repair work could, however, increase the value of products already considered to be commercially re-usable. A simple cleaning would increase the value of a lot of the products.

Hazardous substances were found in re-usable products, but not at alarming levels. Non-metallic toys and household utensils contained lead and nickel in 10 to 35 per cent of the products. Of toys and household utensils made of plastic or textile, bromine was detected in 20 and 25 per cent of products respectively. Laboratory examination revealed negligible levels of PAHs and PFASs in all samples. Phthalates were detected in half the samples but at levels below current legal limits. These findings cannot be used as general conclusions whether any specific kind of product should be re-used or not. The reason for this is that two very similar products may contain different levels of hazardous substances (Hultén et al., 2018a).

3 Methods

A qualitative analysis of the different waste streams in two sorting facilities of the largest private recycling operator in Sweden was conducted for this study. The analysis aimed at assessing the type of waste streams and the quality of waste, to examine if the waste could have been re-used instead of recycled, and assess the potential for re-use of the identified waste streams. The approach in this contribution followed previous studies on the analysis of re-use potential in municipal recycling centres in Sweden (Ljunggren Söderman et al., 2011; Hultén et al., 2018a; Hultén et al., 2018b), however, without quantitatively analysing the samples due to confidentiality issues (business competition). On-site field investigations were conducted in two of the recycling centres of the largest private recycler company in Sweden, accompanied with eight interviews with relevant stakeholders in the recycling and re-use sector in Sweden. The majority of stakeholders interviewed were employees of the recycling company holding various positions, from branch manager to research and development coordinator. Further interviewees were identified through non-probability sampling method (Bryman, 2016), following suggestions or direct collaborating stakeholders of the company. The recycling centres visited are located in Malmö and Kristianstad, both in Scania region in the south of Sweden. The total of eight interviews were conducted with five people from the case recycling company, two people from re-use companies, and one person from the EEE producer responsibility organisation (PRO) in Sweden 'El-kretsen'.

The design of the semi-structured interviews purposefully included open-ended questions in order to capture the diversity of opinion among the different stakeholders in the company. Individual interview guides were used, as the interviewees are engaged in different departments and positions in relation to potential re-use operations, both internally and externally. Due to geographic disparity of the interviewed stakeholders, the majority of interviews were conducted by telephone.

4 Results and Discussion

4.1 Site visits at two recycling centres in South Sweden (Scania)

For the purposes of this study, two recycling centres belonging to the largest recycling company in Sweden were visited (in Malmö and Kristianstad), and their organisation and operations is presented in this section. The recycling centre in Malmö mainly handles iron, other non-ferrous metals, hazardous waste, electronics, paper and plastic. It also handles a small portion of wood waste and rubber. Waste is transported to the Malmö recycling centre from a variety of client companies, but also from other recycling centres across the country that belong to the same recycling company. Iron, aluminium and other metals is treated by cutting it into smaller parts and packing it for shipment to recycling facilities in Sweden and abroad. Also hazardous waste, electronics, paper and plastic are sent on to other recycling facilities. So, the recycling centre acts solely as a sorting and logistics facility, while the actual recycling of materials happens elsewhere.

The recycling centre in Kristianstad differs from the company's other facilities, as it includes a municipal recycling centre within its premises. Private persons come to the recycling centre, as well as companies to dispose waste for recycling. The centre handles about 70,000 tonnes material per year, focusing on so-called alternative raw materials such as building materials, pressure-impregnated wood and garden waste. Building materials are recycled and pressure-treated wood is treated as hazardous waste. The garden waste is crushed and sieved and then composted to soil or turned to biofuel for heating plants. The centre receives also electronics waste, which is then forwarded to the company's major recycling facility in Halmstad.

This recycling centre is collaborating with the social administrative office of Kristianstad municipality, which drives a second-hand store in connection to the recycling centre. There, individuals can leave everything from electronics, furniture and household items to clothes, toys and books. Individuals have the option to dispose items and materials

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in a container for re-use in close proximity to containers for recycling. The items left for re-use are sorted and repaired if necessary, and then the items go on for sale in the store. Cooperation with the social administration means that people with special needs and people in training can receive employment, which contributes to the social aspect of sustainability. The staff working there has shown great appreciation for the collaboration and the work promotes their creative and social development. The second-hand store, which has a large number of visitors, has also become popular among the inhabitants of the municipality and in the rest of Scania region.

4.2 Analysis of interviews

Through the interviews with key stakeholders of the recycling company (internal) and other relevant external stakeholders, a number of common obstacles for re-use were identified, largely consistent with what has been mentioned in literature. Due to the current legal framework, re-use of certain products is not possible. When a product is classified as waste, it is not allowed to be removed from the receiving waste facility and thus not allowed to be re-used. However, it is possible to bring waste under the condition "preparation for re-use" which would allow a product to become re-usable under certain conditions, fulfilling a number of criteria according to EU Waste Directives.

A product's design can make re-use more difficult, especially if it is difficult to dismantle and repair the product (Vanegas et al., 2018). Transport and logistics can also prevent re-use. Many products are damaged during transportation (Cole et al., 2018). For these products it is difficult to estimate any potential for re-use as they are not intact upon arrival at the recycling centre, and effective re-use practices require upstream measures. This is especially true for white goods. Further, for re-use to be economically feasible and profitable there needs to be a certain volume of a specific product (group) and an efficient process to prepare these for re-use. Additionally, peoples' attitude to re-use is considered a significant obstacle. Private individuals may be negatively inclined to re-use due to lack of information about the product and its functionality, or its potential hazardousness (Ylä-Mella et al., 2015). Moreover, it is quite common that people would throw away functional products due to the desire to upgrade their products and acquire the latest version available on the market.

An overarching obstacle to re-use is the additional workload and time it would take to prepare a product for re- use. The product must be sorted out, checked, cleaned, repaired (if needed), quality assured, transported and finally be sold to a customer. The potential product opportunities for re-use identified through the interviews include: 1) building materials, 2) furniture, and 3) consumer electronics. There is also potential to re-use whole white goods, or components in white goods, but this must be done upstream before the goods arrive at the company's premises. Ultimately, the potential for re-use is largely influenced by the type of facility, as it is common that different facilities receive and handle different type of waste.

For materials such as bricks and tiles, there are clear incentives for re-use instead for recycling. This is because the former leads to significantly reduced environmental impacts compared to the latter (Nußholz et al., 2019). Moreover, these materials are relatively more expensive compared to other building materials such as wood and plaster. Increased re-use of construction and demolition waste could be achieved in different ways, for instance through material exchanges linked to either construction and demolition companies or recycling companies. There are several existing platforms that offer such services, which are mainly independent initiatives not being part of construction and demolition companies or conventional recycling companies. Furthermore, focus should be on demolition practices that favour separate collection of building components such as windows and doors, which will effectively increase their re-use potential. However, this can be a costly endeavour that might not be feasible by just one recycling company. Policy support in this area could incentivise the uptake of more selective demolition in the future. Differentiated fees between sorted and unsorted construction and demolition waste disposal could rationalise and balance the higher cost of selective demolition, which today directs demolition actors to prefer conventional demolition practices. Sales of recycled building materials could become a part of the recycling company's business model, for example by cooperating with actors already active in this area (e.g. Malmö Återbyggdepå).

In the case of re-using furniture, transport and warehousing can be complicated and costly, and these consist major obstacles in re-use potential (Öhgren et al., 2019). Transportation and storage of furniture for re-use requires more space and needs to be handled more carefully than material just for recycling. Local solutions for the sale of re- used furniture is an environmental-friendly and cost-effective alternative, compared to a national schemes where the furniture must be transported longer distances. A large amount of office furniture with high potential for re- use usually becomes available when companies are relocated or restructured. Through collaboration with other actors, the recycling company can find opportunities for re-using such furniture before they arrive at the recycling centres, thus avoiding the large and costly transportation to and from the recycling centre. Then, there is potential to cooperate with, for example, moving companies which also transport furniture in a safer manner, avoiding damage of the product. Consumers' preference to divert old furniture for re-use is relatively high, and being offered an easy way to dispose old furniture is considered of great importance.

A major obstacle to the re-use of electric and electronic equipment (EEE) is the desire of consumers to buy new products instead of re-used (Ylä-Mella et al., 2015). Newly made products can also be relatively inexpensive, which makes it economically accessible (Watson et al., 2017). In order to be able to increase the re-use of EEE,

it is important to have secure handling already from the collection stage, as these products can be damaged easily if not handled properly. When EEE arrive in the recycling centres, it is usually too late to restore or dismantle them, as it is often not economically desirable. In addition, there is uncertainty about the products' performance and safety. EEE may have been disposed due to electrical faults, which can lead to fire risk and danger for further use. One incentive for re-using electronics is to provide a warranty or quality label on the re-used product (Gåvertsson et al., 2018). In this way, the customer can feel safe because the product is guaranteed to work properly for a certain period after the purchase. This is something that companies working exclusively with re- use (repair and remanufacturing services) can readily offer, but it might be more difficult for a recycling company to provide – let alone costly. However, there is still potential for salvaging components of damaged EEE that are still operational and can find a second life as spare parts on the market, provided prices can match the costs of operations (dismantling, cleaning and forwarding to the market) performed by the recycling company.

4.3 Actions for increasing re-use in private recycling centres

The private recycling company that has been studied in this contribution would firstly need to focus on re-use opportunities from waste received directly through industrial partners rather than what comes from recycling centres with unpredictable and heterogeneous waste flows. Thus, it can reap the readily available opportunities and work with customers to develop business agreements that favour re-use. Materials sorted out for re-use from private individuals and other customers at recycling centres are of varying quality and often require further processing, which is labour intensive.

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Additionally, the private recycling company could focus on products identified in its recycling centres by this study, including re-use of bricks and tiles, furniture and white goods, to the extent possible. EEE in the company's recycling centres are difficult to re-use, however, there is some potential for white goods. Cooperation with other companies is seen as a key action, for example with El-Kretsen (PRO) and BVV (second-hand company), to enable the re-use of white goods. Establishing an on-line platform for sales of white goods is a step in the right direction. The most important issue about both furniture and EEE is that the handling of the products is done carefully.

It can be problematic for a recycling company to handle at the same time sales, repair and storage of products and materials for re-use, as it is not included in the company's current business model. However, the company could act as an intermediary in the re-use process, by sorting out the products and materials that could be re-used and forward them to other actors who are responsible for repair and sales of second-hand goods. This requires further development of the current business model of the company and its logistics solutions. Moreover, collaboration with diverse actors is required, while also finding mutual profitability within the network and the re-use process. One barrier is that it requires time and resources to develop new business models, therefore investments must be able to be repaid through the re-use process. The operations may run at a loss until more efficient processes and larger volumes are established. Another difficulty is that the process involves many steps and actors with different costs for both work and transport. The profit margin can therefore be small, if there is not high enough value remaining in the products at the secondary market. Some products received at recycling centres may have a low purchase price and therefore reflect a low value in the secondary market. So, it does not become economically viable to repair and sell these products. Interestingly, our interviews with PROs have revealed that in the case of white goods there may be more value in single components that in the entire good. This is due to the fact that the

breakdown of a white good tend to be caused by single components. Access to components can therefore support repair activities, as new repair parts attend to be very expensive.

However, it can be profitable with re-use of products that have a higher value in the secondary market, such as electronics, furniture and higher quality building materials. This is because these products can be more expensive to purchase new rather than used. Special potential for re-use is available for materials that appear in large volumes, as this means a more predictable flow that can be managed more effectively. Finally, company executives believe that re-use can become profitable in the future, but changes in society's attitude to re-use are required, as well as policies that makes re-use more attractive. Ultimately, in line with increased environmental public awareness, re-use of products will increase in the future, which means a reduction of material flows to recycling companies. For this reason it is recommended to take advantage of the business opportunities that exist within re-use.

5 Conclusions

Within a circular economy context, EU Member States strive to ascend the 'waste hierarchy' and retain materials and energy in the economy by re-using products as much as possible. The majority of EU members have achieved relatively high recycling rates but the next challenge in waste management is how to prevent waste, including promoting re-use of EOL products.

This contribution consists a basis to design and develop re-use operations in recycling centres in Sweden and potentially internationally. It shows that there is a great potential to collect and re-use more products that are currently only being recycled. The potential for increased re-use is demonstrated both in municipal recycling centres (public), by analysing previous studies, but also in private recycling centres operated by large recycling companies in Sweden. Achieving higher re-use rates is not only a public responsibility, but private enterprises have also a critical role to play. Therefore, the focus in this study was on the private sector and on how a "traditional" recycling company can find opportunities to adopt a more circular business model and include re- use in its operations.

About a quarter of the waste collected in recycling centres can be commercially or at least functionally re-used, resulting in significant environmental and social gains with inconclusive economic benefits. Product groups with the highest re-use potential in private recycling centres are building materials, furniture and EEE. However, taping on this potential, private enterprises are required to explore new types of collaborations both with other private actors and public authorities. Increased collaboration and prioritisation of suitable product groups and market opportunities could effectively increase re-use in the future.

Consequently, a more integrated investigation would be beneficial to determine the conditions of such collaborative actions. Therefore, future research could expand on this study by quantifying the flows of re-usable products in more recycling centres (both public and private) and map out the re-use dynamics at a regional or even national scale. Furthermore, a wider market investigation in the potential market demand and supply of re- used equipment both domestically and internationally could enable a more comprehensive economic analysis.

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Is It Worth It? Repair of Household Appliance, Mobile Phones and Clothing

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Abstract

Increasing product lifespans is one of the most effective environmental strategies, as it has a potential to slow down the consumption cycle and thus prevent waste, and reduce production and transport. Products that get broken get their lifespans shortened, and consumers can choose whether they will try to repair them or not. From an environmental point of view, it is usually profitable to repair the items, but consumers also consider other aspects. This paper explores consumers' experiences with repairing household appliances and clothing. Are there differences between clothing and electronic products in terms of how common it is to repair them, who chooses to repair them and why, who conducts the repairs, and how successful are the repairs? This paper is based on a consumer survey of 1196 respondents conducted in Norway between December 2018 and January 2019. The aim of the survey was to map which household products are repaired, and consumers' motivations and barriers to repair and use of repair services. Our results show that it was more common to replace home appliances and mobile phones than to repair them when they broke, and additionally, over half of the attempts to repair failed. Clothing repair was successful to a much larger degree. Repairing yourself, or getting help from someone you know is quite common for all the product groups we included in our survey. This dominated repair of clothing where it was three times more common than using professional repairmen, while it constituted about 37% of repairs of mobiles and appliances. Results indicate that for both clothing and other goods, better products are what can contribute to longer life. Higher quality means that a product can be used longer before it needs repair, but in addition, better quality will also increase the profitability of repair and make it more worthwhile. Price and availability of repair services are also important for repair of goods, especially for mobiles and appliances. This has political implications on how to promote longer product lifespans in production and through repair.

Keywords: Repair, Product Lifespans, Consumer Behaviour, Clothing, Household Products

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1. Introduction

Increasing product lifespans is one of the most effective environmental strategies, as it has a potential to slow down the consumption cycle and thus prevent waste, and reduce production and transport. When products are broken, their lifespans shorten. The need to repair can be caused by errors or deficiencies obtained before use during manufacturing or transport, or it can be caused by wear and tear, either because the product has been used for a long time (extensive wear) or because it has been used incorrectly, unintentionally or accidentally. Appropriate maintenance can prevent damage to products. For several product groups, there is often an overlap between repair and maintenance. For clothing, there can be an overlap between repair and modification or customization of the product to fit the user's body, taste or other needs. There is not a clear distinction between repair and customization of clothes and we have therefore chosen to include both in the study.

From an environmental point of view, it is profitable that a larger portion of defect products are repaired so that they remain in use longer (Downes *et al.*, 2011; Montalvo *et al.*, 2016). The decision to repair the items is mainly placed on consumers, who also have to consider other aspects, and they can choose whether they will try to repair the items or not. In the UK, 26% of consumers report that they usually have their appliances repaired. This means that the remaining majority repair only rarely, seldom or never (Cooper, 2004). However, the repair rates are likely to vary between different types of products, and few studies have looked into systematic comparisons between different products.

Most studies on repair activities focus on repair services provided by the professional instances, especially within consumer electronics (Adler and Hlavacek, 1976; Gerner and Bryant, 1980). Some studies on clothing also focus on private repair (Gwilt, 2014; McLaren and McLauchlan, 2015) and prosumption aspects as part of Do-It- Yourself (DIY) movements (Gelber, 1997; Williams, 2004; Watson and Shove, 2008; Eden, 2017), but there are very little studies that focus on comparison of these two forms. Norwegian Consumer Council reports that consumers mainly attempt to repair clothing and furniture by themselves, while it is more common to use professional services for repair of electrical appliances (2019).

Ekström *et al.* (2012) interviewed various consumer groups in Sweden, and their results indicate that especially elderly were concerned about clothing repair, and conducted simpler repairs themselves while also using tailors when larger repairs was needed, such as change of zipper, or customizing clothing for improved fit. This was not quite as common among the younger consumers, but they too did undertake some simpler repairs, especially of jeans. Families with small children had seldom time to repair clothing, and thus it was not a prioritized task.
Consumer studies also indicate that the result of repair attempts is not always satisfactory. In the US, as many as 40% had at least one gripe about repairs and 25% had been dissatisfied with the outcome of a repair (Consumer Reports, 2001, 2005). This has also contributed to that many survey participants refrained from repair services as they considered it as too 'shoddy work' (Consumer Reports, 2001). This negative perception of manufacturers and repair industry can contribute to increasing consumers' perceived inconvenience of repair and lack of trust in repair shops (Lilley *et al.*, 2013; Lefebvre *et al.*, 2018).

Many studies have also focused on barriers to repair, and for example McLaren and McLauchlan (2015) divide them into practical, social, socioeconomic, systemic and psychological barriers. Most commonly identified aspects are financial costs, lack of time, and skills. However, Middleton (2015) points out that for example minor mending of textiles only requires needle and thread, and not that much time and only basic skills. Use off professional repairmen can of course be more costly. McCollough (2009) tested various economical factors' contribution to a number of workers employed as television service technicians 1980-2000 in the US. He found that cost of the new product was more important than the cost of repair. That is, cheap new product prices decrease likelihood to repair. This was also confirmed by Consumer Reports (2001), where 34% of survey respondents decided not to repair due to falling replacement prices. According to McCollough (2009), other factors that contribute significantly are the amount that is used yearly on advertising new products, as it informs consumers
about latest technologies, design and functionality features, thus having negative impact on repair intention. Surprisingly, GDP growth rate was positively correlated to repair. Usually it is assumed that in recession, people would repair more, but it seems they may try to save money on repair costs and attempt to repair by themselves instead. McCollough (2007) propose that increase in income reduces the likelihood to select reuse due to consumers feeling their time is more valuable and are less likely to use it on repairing and maintaining products. Other identified barriers that were not included in the mathematical modelling were the perceived travel and waiting time, cost of frustration and annoyance that increases between product breakdown and completion of service. Also confidence to repair, as in expectation that repair will be completed correctly and give additional useful life after repair, is of importance.

Most literature indicates that consumers are willing to pay about 20% (McCollough, 2007) or 19-24% (Adler and Hlavacek, 1976) for repair in correlation to the replacement price of these types of household appliances. However, decision to repair is not solely dependent on economic factors. Emotional attachment to a product can contribute to the owner wanting to repair it, even if the market price does not indicate this as profitable. The opposite can be observed in the contemporary consumer culture where there is a sense of detachment from products that offer little emotional attachment and are low priced, and therefore not considered worthy of repair (Chapman, 2005). Emotional factors may also stand in the way of repair because this is a practice that can be connected to economic hardship and negative associations, such as stigma (Fisher *et al.*, 2008; Kelley, 2009).

This paper aims to filling knowledge gaps by exploring consumers' experiences with repairing household appliances and clothing. Are there differences between clothing and electronic products in terms of how common it is to repair them, who chooses to repair them and why, who conducts the repairs, and how successful are they? In addition, we look into consumers' motivations, as in which factors contribute in evaluating whether something is "worth" to repair, and what could thus contribute to longer lifespans.

2. Method

This paper is based on a consumer survey of 1196 respondents conducted in Norway between December 2018 and January 2019. The aim of the survey is to map which household products are repaired, and consumers' motivations and barriers to repair and use of repair services. The target group was the Norwegian population aged 18-80. The sample largely follows the population by region, gender and age, but is additionally weighted so that it is

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representative of these three variables. Demographics of the respondents are presented in Table 1.

Table 1. *Demographics of the respondents.*

Demographics		Per cent
Gender	Men	50 %
	Women	50 %
Age group	18-29	21 %
	30-44	26 %
	45-59	26 %
	60-80	28 %
Employment status	Work fulltime	47 %
	Work part time	7 %
	Self-employed	3 %
	Retired	19 %
	Unemployed	2 %
	Other type of social security	9 %
	Student	11 %
	Homemaker	1 %
	Other	2 %
Education	Primary education	5 %
	High school – general studies	16 %
	High school – vocational studies	16 %
	Vocational education (1/2 – 2 år)	9 %
	University / college education (≤4 years)	29 %
	University / college education (>4 years)	24 %
Personal yearly gross income	Less than NOK 200.000	14 %
	NOK 200.000 - 299.999	9 %
	NOK 300.000 - 399.999	14 %
	NOK 400.000 – 499.999	19 %
	NOK 500.000 - 599.999	14 %
	NOK 600.000 - 699.999	8 %
	NOK 700-000 - 799.999	5 %
	NOK 800.000 - 999.999	4 %
	More than NOK 1.000.000	3 %
	No answer	9 %
Household	Spouse / cohabitant	37 %
	Spouse / cohabitant and children	24 %
	Living with my children	4 %
	Living with my parents	7 %
	Living alone	21 %
	Shared housing	5 %
	Other	1 %

3. Results and Discussion

3.1. Electrical appliances

Many respondents had experienced that their electronic products had broken. Of the electronic product groups we focused on, respondents had experienced that mobile phones were most frequently broken during the past two years (28%), while 12% had experienced a broken dishwasher or washing machine, and 10% or less a broken refrigerator, freezer, or stove (Fig. 1).

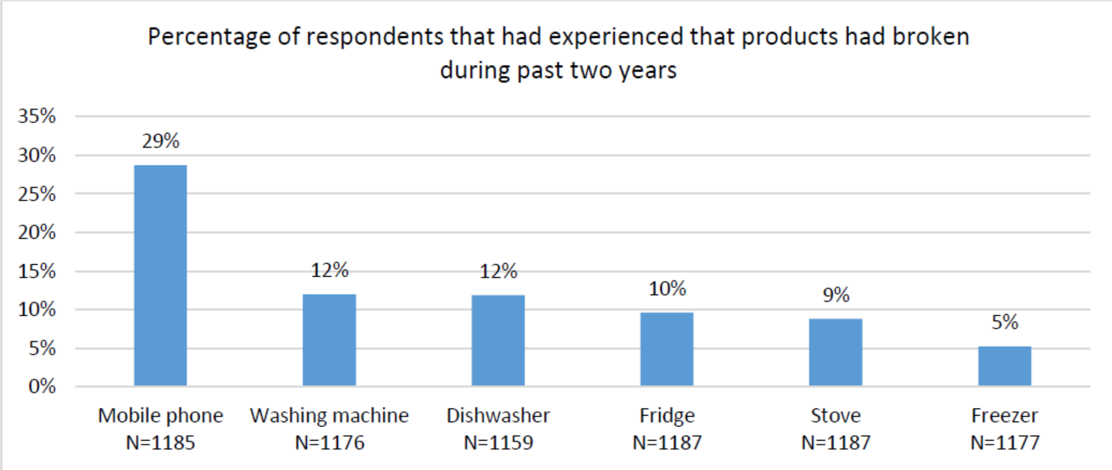

Figure 1. *Percentage of respondents that had experienced that products had broken during past two years (Percentage of those that owned or had access to product type in question).*

Less than half of these broken products were attempted to get repaired. It was most common to try to repair a washing machine (47% of those that got broken), and least common to repair a freezer (20%) (Fig. 2). Even though something breaks, it does not always mean that the product is taken out of use. In our material, 8% of broken mobile phones and stoves were still in use despite their faults, indicating that they retained some functionality. It is likely that these cases could include phones with broken screens and stoves where maybe one of the plates or functions in the oven are faulty. Less than 3% of the other product groups were kept in use while broken. This is plausible, since these products have fewer separate features and are therefore more likely to be useless when some of their functions get broken.

Not all repair attempts are successful. There are surprisingly many unsuccessful repairs, as almost half of the repair attempts failed (Fig. 2). Over half of the repair attempts of washing machines, dishwasher, mobile phones and fridges failed, and only stoves and fridges had more successful repairs than failed. When combining results from all these broken products, an average shows that 15% were repaired successfully, 19% were attempted repair but failed, 60% were not even attempted repair, and 5% were used further despite the fault.

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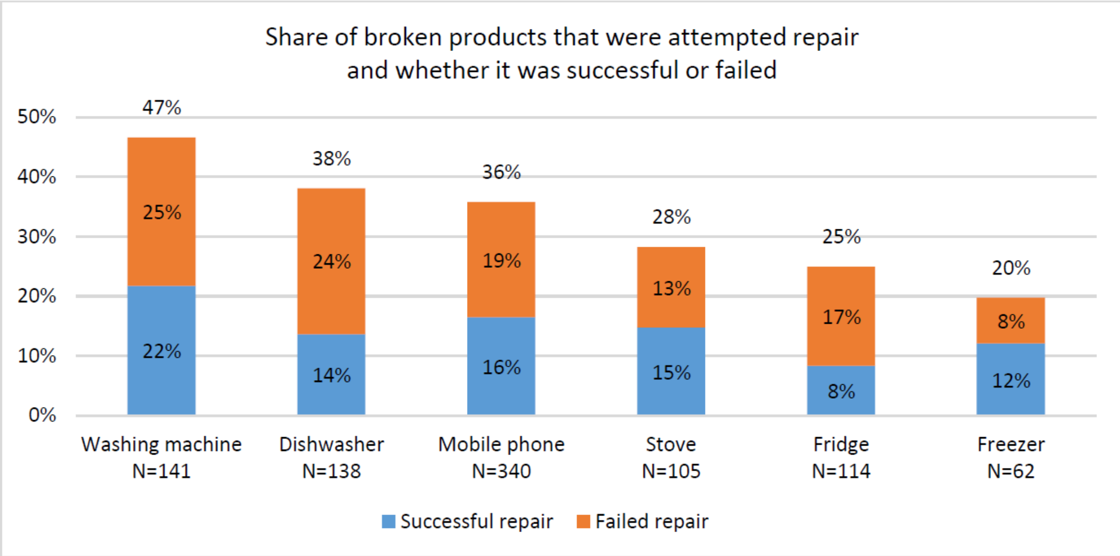

***Figure 2**. Share of broken products that were attempted repair and whether it was successful or failed.*

Due to small number of responses within each product category, the responses for the different household appliances are combined in the further analysis, while mobile phones are kept in a separate group. When examining who repaired the products, we see that several instances were used, and all of them have both successful and failed outcomes (Fig. 3). For both product groups, the success rate is higher by the professional repairmen than in the private attempts. For mobile phones, only 28% of private repair attempts are successful compared to 55% by the professionals, and similarly 39% of the private repairs of household appliances as opposite to 48% of the repairs by professionals. When comparing the specific professional repair instances, the stores and producers have highest success rates (70% and 73%) in repairing household appliances, while other repair specialists only succeeded in 30% of cases. This was different for mobile phones, as repair specialist succeeded in 57% of cases, tightly followed by stores and (56%) and producers (50%)

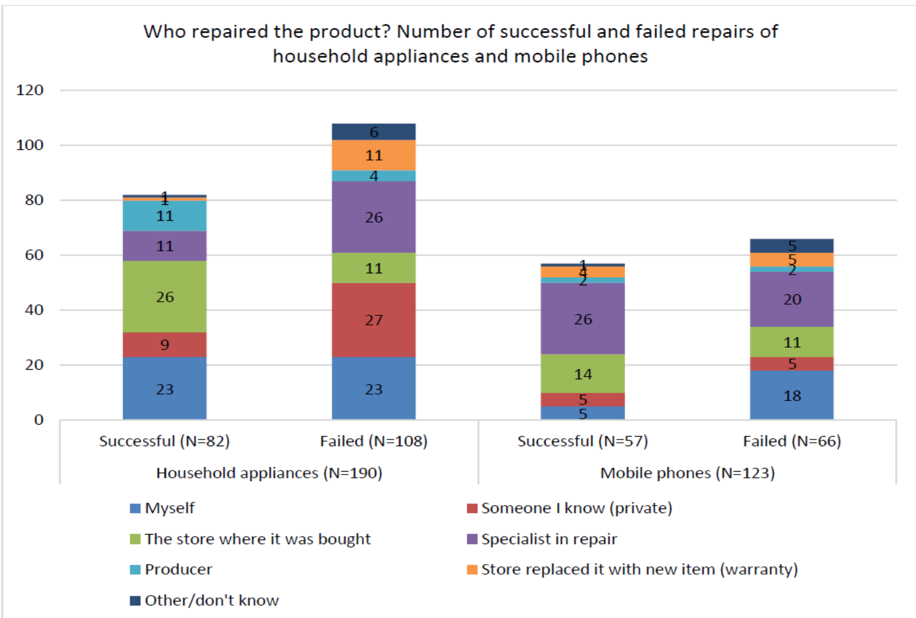

***Figure 3**. Number of repairs by who attempted repair and whether it was successful by main product groups (household appliances and mobile phones).*

An interesting category is "Store replaced it with a new item (warranty)", because some respondents have interpreted this as successful repair, while others have reported it as failure. This may be because the repair itself failed, but the complaint process during the warranty period has been successful.

Many of the reasons for repair were equally important for home appliances and mobile phones, while some stand out (Fig. 4). Price and quality of the broken products were particularly important reasons for repairing appliances, while for mobiles it was whether the owner liked the mobile, and that it was new. Every fifth respondent has also replied that environmental considerations were important in choosing to repair. We should add here that many of the questions in this survey were about environmental issues, so this perspective may have been high up in the respondents' consciousness.

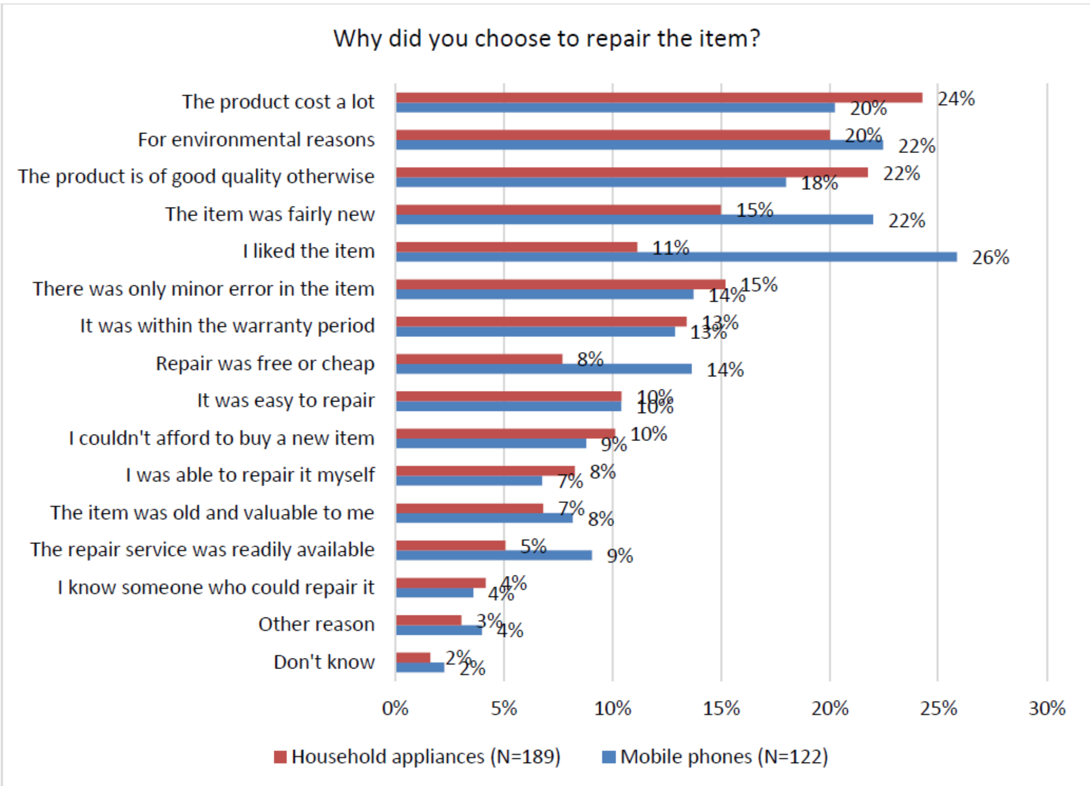

***Figure 4.** Reasons to repair household appliances and mobile phones Respondents could select up to three reasons. Percentages by respondents.*

We found some significant differences between respondents (significance level $p<0.05$). Men were significantly more likely to repair appliances because they were easy to repair, they were able to do it themselves, or because repair was cheap or free of charge, while women were more likely to know someone who could repair it. Students were more likely to repair items if they were expensive, while those with lower or vocational education were more likely to give existing warranty as a reason to repair. Those with low income were more likely to repair if they knew someone who could repair the item. Single parents, households with lower incomes and those living on social

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security were more likely to say they could not afford to buy a new product.

We asked about the reason for why broken products were not repaired (Fig. 5). The main reason was that the product was too old or too damaged to be repaired. Also important was that repairs were expensive and it was cheaper to buy a new product. Larger share of respondents reported wanting a new mobile phone (19%) than a home appliance (8%), and 7% thought repair services were poorly available. We thus see that product related aspects are most important ones for goods not being repaired, rather than the price and availability of repair services, although these were also important to some. We also found some significant differences ($p<0.05$) between respondents. Young respondents answered more often that they did not have time or energy to govern with getting things repaired, and similarly students reported this reason, but in addition to not considering repair as an option, and poorly available repair services as important reasons. Respondents in higher age groups more often reported the products being too old to be worth repair.

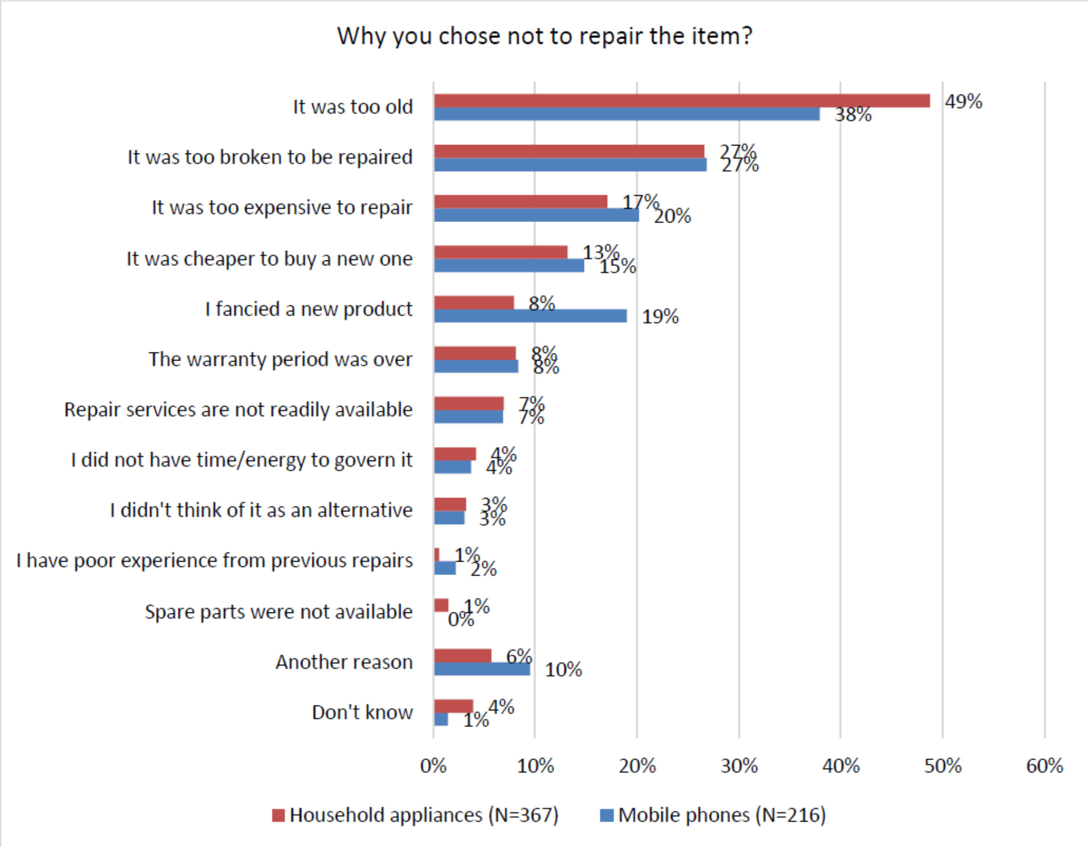

Figure 5. *Reasons for why household appliances and mobile phones were not repaired. Respondents could select up to three reasons. Percentages by respondents.*

3.2. **Clothing**

Clothes differ from electrical household appliances in several ways. In general, consumers only have one of each of the mentioned appliances, while their wardrobes may consist of hundreds of garments (Klepp and Laitala, 2015; Klepp *et al.*, 2019). Although all of the products we focus on are usually privately owned, the use of larger household appliances is shared within the entire household while use of clothes and mobile phones is dominated by one particular person, although they can also be used by several people (Klepp and Laitala, 2018). While a broken fridge or freezer in most cases will cause major inconveniences in daily life, a broken garment will not cause an acute crisis or immediate need for replacement as most people have alternative garments available. In addition, the knowledge and the techniques needed to repair the aforementioned products is also pertinent.

As expected, the picture is quite different when we look at repair of clothing compared to repair of household products. There are much less unsuccessful repairs. When asked "Have you got any of your clothes repaired or adjusted in the last two years?", 41% replied that they had, 3% had tried but that the repair was not successful, and 56% had not repaired or adjusted any clothing. Figure 6 shows the distribution of those that had clothing repaired or adjusted by gender and age group.

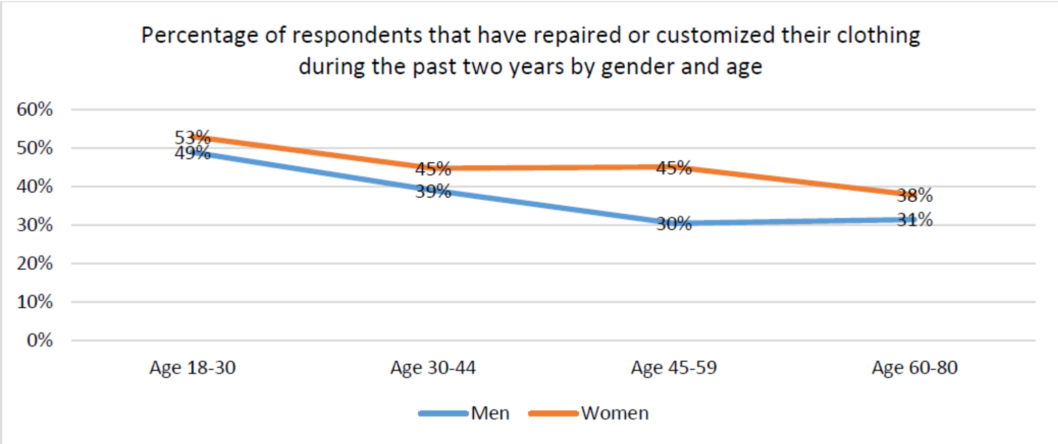

Figure 6. *Percentage of respondents that have repaired or customized their clothing during the past two years by gender and age (N=1196)*

From previous studies, we know that the term «repair» of clothing does not necessarily cover all types of repair, because a high percentage of respondents who said they «never repair clothing» also said they have done repairs such as sewing on a button (73 %) or fixing an unravelled seam (55 %) (Laitala and Klepp, 2018). This suggests that making such minor repairs are not considered as "proper" clothing repair. Therefore, there are likely to be a larger share of respondents who had performed repairs themselves than the answers indicate. The same may be valid for customization and adjustments, but we have not found previous studies that would document this aspect, for example by looking into the relationship between those who respond that they have not customized clothing but at the same time shortened trousers. We can still assume that more than those who respond will have made simple adjustments of clothing. Thus, for all the answers, we have reason to believe that they are low in relation to the realities. They are nevertheless suitable for discussing the questions we raise in this paper.

There is a significant difference between genders, as 48% of women had had their clothing repaired or customized during the past two years, while only 39% of men answered the same. Another tendency we found was that older people had more seldom their own clothing repaired or customized than younger people, but at the same time, younger people received more help from family/friends to repair their clothing (Table 2). We know that number of articles that disseminate knowledge about clothing (Døving and Klepp, 2009) and mending (Klepp, 2000) has reduced in textbooks, handicraft books and weekly magazines, and we can therefore assume that older consumers have more existing knowledge than the younger consumers. The reduction in textile skills is especially valid for men (Klepp, 2005). However, younger generations are used to go on internet searching for information such as

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"How-to" videos on YouTube, and thus has a potential for easily acquiring new skills (Burgess and Green, 2018). Knowledge is one factor but just as important is the need for repair. We know that seniors use their clothes longer (Langley *et al.*, 2013). However, the elderly do not wear out their clothing to the same degree than many other more active users, such as children, do (Berggren Torell, 2000).

Figure 7 shows that it is far more common to repair clothing privately than electrical appliances. The most common form was that the respondents repaired the item themselves, but many also had help from family and friends. There is also a significant difference in success rate when compared with repair of electrical appliances, both in private and professional repairs. One big difference from the electrical appliances is that producers and retailers have a much smaller role in repairing clothing. To the extent professional services are used, it is by companies that are independent of the production and sale of the products, namely tailors.

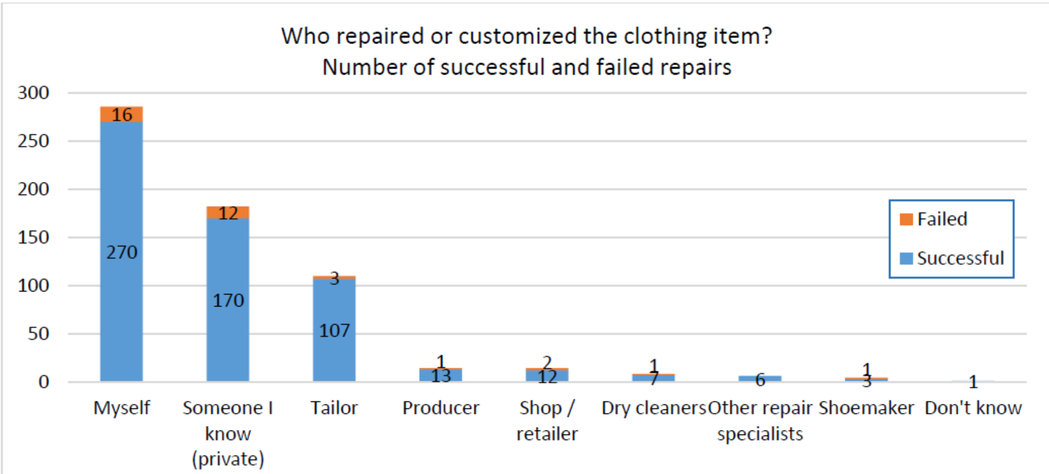

Figure 7. *Who repaired or customized the clothing item? Number of successful and failed repairs*

Of the 43% of respondents who had repaired or attempted to repair clothing over the past two years, 72% had done this by themselves or through someone they know, 18% had used professional services, such as tailors or delivered to the store, and 11% had used both forms. This means that private clothing repair is at least three times more common than using professional help. We do not know anything about the number of clothes that have been repaired, but assume that the quantity is larger when done privately. In this case, this implies that the difference in the number of repaired garments is greater than the difference in the number who use professional versus private solutions. This means that private repair probably is even more common than the results show. This is likely due to differences in the reported numbers in addition to under-reporting of simpler repair tasks such as sewing on buttons or fixing unravelled seams.

Table 2. *Who repaired or customized the clothing item? Share of respondents that had repaired or attempted repair the alt two years divided by gender and age group. Several answers were allowed. N=516 (Results that are given in bold italic are significantly different within the group with p<0.05).*

	Total N	Percentage of repairs	Gender		Age group			
			Women	Men	18-29	30-44	45-59	60-80
Myself	287	55 %	***74 %***	***32 %***	56 %	54 %	59 %	54 %
Someone I know (private)	182	35 %	***26 %***	***47 %***	***47 %***	***37 %***	***24 %***	***32 %***
Tailor	110	21 %	***17 %***	***27 %***	16 %	25 %	24 %	20 %
Producer	14	3 %	2 %	3 %	***5 %***	***4 %***	***2 %***	***0 %***
Shop /retailer	13	3 %	2 %	4 %	3 %	2 %	1 %	4 %
Dry cleaners	9	2 %	2 %	1 %	1 %	3 %	1 %	2 %
Other repair specialists	6	1 %	1 %	2 %	1 %	0 %	1 %	3 %
Shoemaker	4	1 %	0 %	1 %	0 %	1 %	1 %	1 %
Don't know	1	0 %	0 %	0 %	1 %	0 %	0 %	0 %

We were also interested in what could contribute to longer use of clothing. We gave our respondents a series of statements about what might make them wear their clothes longer (Figure 8). There was only one statement where the average of respondents agreed; namely that clothes would be worn longer if they were of better quality. This statement was followed by "if repair services were cheaper", which 32% of respondents either fully or partially agreed with.

The statement that respondents agreed the least with was that they would wear their clothes longer if the fashion did not change so often. This is in line with previous studies of Norwegian dress habits (Laitala and Klepp, 2013; Klepp and Laitala, 2016).

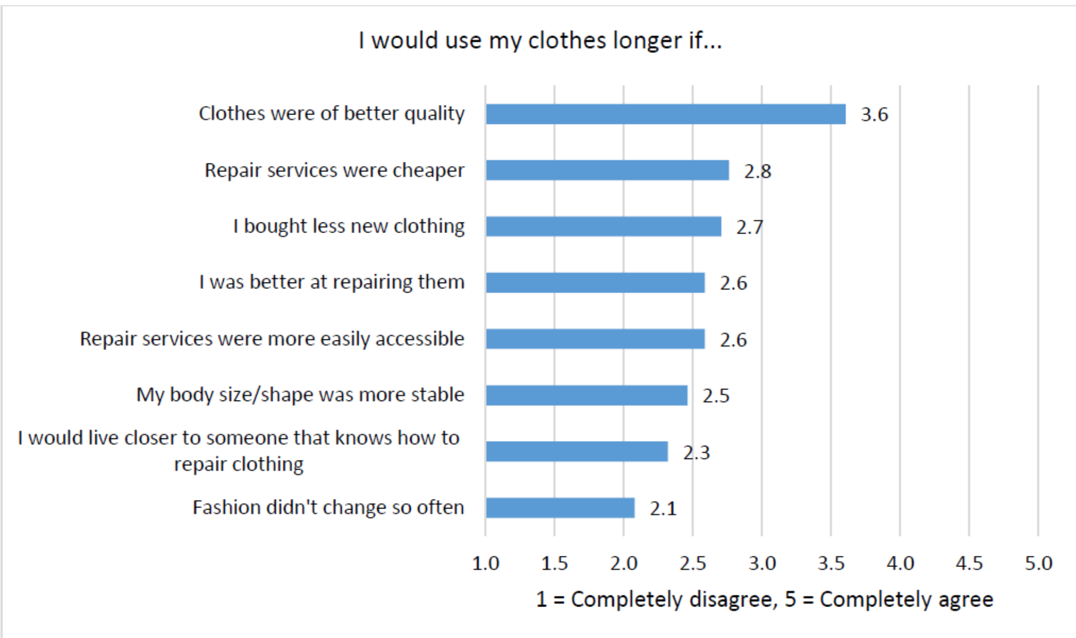

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***Figure 8**. What could contribute to you wearing your clothing longer? Average values of scale from 1 to 5, where 1= completely disagree and 5= completely agree.*

4. Conclusions

In the start of this paper, we asked if there are differences between clothing and electronic products in terms of how common it is to repair them, who chooses to repair them and why, who conducts the repairs, and how successful they are.

Our results confirm that many people experienced that their products had broken during the past two years, especially mobile phones, where 29% of respondents reported this. It was most common that home appliances and mobile phones were not repaired. On average, 15% of the defect electrical appliances in the survey were repaired successfully, while approximately 19% were attempted repair, but the repair failed.

Being able to repair something through use of private channels, the cost entails allocating time, and the prerequisite is to know someone with the repair skills. For all the product groups we have asked about, repairing yourself, or getting help from someone you know is quite common. For mobile phones and home appliances, this amount to approximately 37% of the repairs, while for clothing private repairs dominate. Three times as many replied they have repaired privately than used professionals. The difference is probably even greater. Clothing repairs were more often successful than repair of the other products.

For both clothing and other goods, better products are what can contribute to longer life. For mobile phones and home appliances, old poor products are the main reason to not repair the products. One of the main reasons why the goods were repaired was that they were otherwise of good quality or high-priced. The only statement concerning what can help make clothes last longer, that a majority of respondents agreed on, was that clothes should have better quality.

Price and availability of repair services are also important for repair of goods, especially for mobile phones and home appliances. For clothing, the extent conducted privately is much greater than professional services, and measures here will have a potential to increase the scope even more.

Higher quality means that a product can be used longer before it needs repair, but in addition, better quality will also increase the profitability of repair and make it more worthwhile. This has political implications on how to promote longer product lifespans in production and through repair.

There is a lot we do not know about repair. What makes so many repairs on home appliances and mobiles unsuccessful? What kind of repairs are being done privately and how can they get even better results?

Our research has still contributed with new knowledge. Even though clothes, mobile phones and household appliances are very different product groups, the results are strikingly similar between them. It is therefore good reason to believe that our results will apply to a variety of other consumer goods as well. Our most important result is that better products are crucial for what will lead to more successful repairs and thus longer life and reduced environmental impact.

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Bought today gone tomorrow – Product obsolescence as a challenge for green consumption

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Abstract

Current production and consumption patterns in industrialised countries are characterised by an immense growth in personal properties, an increasing equipment of everyday life with electronic gadgets and infinite loops of new product generations. Short-lived products play a key role in these practice formations and are a challenge to sustainable systems of production and consumption. Since 2011, the so-called product obsolescence, a term describing the premature depreciation of consumer goods, enjoys constant media attention. Common discourses around obsolescence presume a deceit of producers who are suspected to inscribe a pre-calculated expiry date into their products. The presentation goes beyond this linear cause-and-effect perspective and discusses obsolescence as an outgrowth of modern material culture and unsustainable human-object relationships. Results of various studies into modern production and consumption practices and procedures are reported, like insights from a media analysis on obsolescence communication as well as from a consumer surveys. Conceptual ideas will be presented that deconstructs obsolescence as communicatively and materially constructed in interrelated practices of designing, creating, appropriating, (d)evaluating and disposing consumer goods. A main point is that both, the social significance and meaning projected onto objects and the practical understanding concerning the object's materiality and functionality are key issues to understand and overcome unsustainable product lifetimes.

Keywords: Sustainable Consumption, Product Obsolescence, Social Practices, Inscription, Description

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1. Introduction

"We live in a throwaway society." This - often fatalistically connoted - statement is constantly expressed in interviews, surveys or media discourses on the subject of modern consumer culture. Correspondingly, in a survey from 2017, 94% of the participants agreed to the according statement (Jaeger-Erben& Hipp, 2017). [2]

If one were to believe this perception, the question of the social drivers of product obsolescence, i.e. the too short useful life of consumer goods, would be answered very quickly: Disposable production and disposable consumption go hand in hand and are symptomatic of a modern, negligent use of finite resources. This perception has a counterpart in the material reality that presents itself in the form of "gigantic mountains of electronic thrash" and an "incalculable trail of hazardous waste" (Oetzel 2012, translation by author). 3.5 million tonnes of waste were produced worldwide every day in 2010, and this figure is set to almost double by 2025 and to triple by 2100 (Hoornweg et al., 2013) . In 2015, 13.5 kg of waste per person per day were generated in the EU alone (Eurostat 2014), with electronic waste as a big and steadily growing part of it. For example, 50 million tonnes of electronic waste will probably be generated worldwide in the coming year (Wang et al., 2013). Thus: Is the diagnosis correct? The term "throw-away society" was framed in the second half of the 20th century (see for example Packard, 1960) and was constantly referred to in the context of growth- and consumption-critical debates that followed. There is talk of a cultural "throw-away mentality" and it is observed that the amount of consumer goods and particularly electronic devices in everyday life constantly increases (Oetzel, 2012).

But terms such as "throw-away society" scratch only on the surface of the modern consumer culture. In fact, the amount of waste per capita per year is increasing worldwide, but national trends vary greatly from one country to another and even decline in some countries as consumption historian Trentmann (2016) records in his history of consumption. Trentmann also investigates hoarding, collecting and storing as a form of disposing of consumer objects and states: "The impulse to hoard things was much greater [towards the end of the twentieth century] than the tendency to throw things away." (2016: 891 , Supplement by author). Thus, throw-away society is neither an apt description nor an explanation of the socio-cultural causes of obsolescence. In the following, we will report some conceptual reflections as well as empirical results from our interdisciplinary esearch on the causes and drivers of obsolescence of consumer goods, particularly electronic devices. A basic conceptual differentiation is that obsolescence should be approached with a:

1 Focus on material manifestations: The too short life of products manifests on the one hand materially, for example, in the disintegration of the material and the loss of originally planned functionality, but also in the acceleration of material flows or the height of electronic waste mountains.

2 Focus on manifestation in communication and discourses: On the other hand, the lifetime and useful life of products is the subject of social discourses dealing with social and technological change and the consequences of modern forms of production and consumption. Obsolescence is also a matter of negotiation and allocation of meanings, values and norms.

Both manifestations of obsolescence are closely related, but sometimes the discourse is disconnected from material reality and tends to become independent, which can be challenging for overcoming obsolescence or promoting sustainable production and consumption, as we will see in the following. In this paper, we will describe discursive and material practices in (re)producing obsolescence based on conceptual and empirical insights. Finally, the problem of one-sided or linear explanatory models and causal attributions is pointed out and a systemic perspective on obsolescence is sketched.

3. Obsolescence as a social construction

The confrontation with the value of consumer objects and a certain discomfort in view of growing mountains of waste is not a modern phenomenon. While in the mid-twentieth century it was rather a fear of decadence and waste, nowadays it is more of a concern over increasing pollution (Trentmann 2016: 836) that causes discomfort.

The history of obsolescence is a history of the relationship between society and its consumer goods that is reproduced in social practices of consumption and production. Throughout history, the value of a product and the corresponding diagnosis “useful” or “obsolete” has changed almost independent from how the design or material properties of a product changed. For example, even though durable consumer goods such as an electronic mixer got more complex in their function and more resource-intensive in their production, their value did not increase in general. On the contrary: Globalised mass production and the pervasive availability of electronic consumer goods have led to a massive decline in the monetary and practical value of the single device.

Becoming obsolete is not a natural process but a process of actively devaluating and invalidating an object until being no longer useable or useful. What is considered as useless and no longer worth preserving - for example, through repair, upcycling, functional or aesthetic reuse - is therefore also the result of a social construction and not a predefined property of a consumer object that is determined by the product developer or manufacturer. Thus, in this social constructivist reading, there is no clear distinction between absolute or relative obsolescence - as Cooper (2004) suggests – because it is always relative in the sense of a comparison between obsolete / useless / dysfunctional and non-obsolete / used / desired / functional.

A more social constructivist perspective is also reflected in Science and Technology Studies (STS) that define consumer goods as something that is actively produced or transformed to an object of consumption and commodity in the course of its useful live. “Consumer goods are neither finished nor invisible forms at the points of production and acquisition, but [...] continuously evolving, positioned within and affected by an ongoing flow of consumer practice." (Gregson et al., 2009: 250). Although certain usage modes and the range of object performance are to a certain extent inscribed into an object ("inscription" Akrich 1992), it is the practice of usage that constitutes what an object becomes. Thus, the user or consumer might overwrites what was inscribed by design ("description", ibid.) as the object is used and here it is decided whether the intended uses and services are actually realized. Product designers and users are thus connected; their knowledge, their expectations and their practices indirectly interact with each other via the object.

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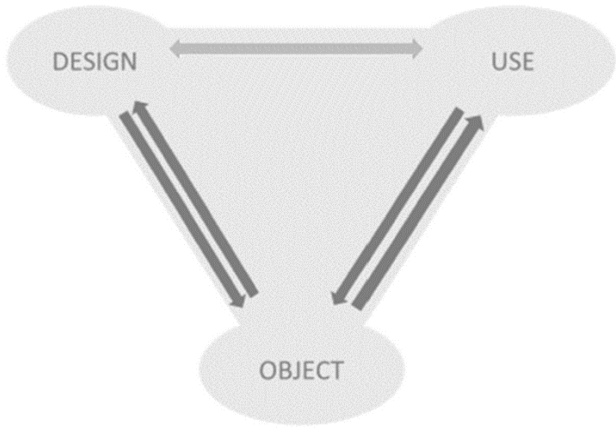

Figure 1: In order to understand social drivers of obsolescence, the "triangular relationship" of design, use and consumer object must be taken into account

An analysis of the social drivers of obsolescence thus has to decipher the dynamic "triangular relationship" (Figure1) of design, use and object in a context-sensitive approach and needs to relate to both: the discursive and the material manifestation of obsolescence. However, as described in the following public discourse, and sometimes even scholarly debate, tends to be more of a linear and one-dimensional understanding of obsolescence..

4. The Communication of Obsolescence - Insights into Media Discourses

In public discourse, obsolescence is mostly perceived as "planned" or "enforced obsolescence", i.e. a premature passing of a consumer good. The term itself experienced its first significant mentioning in the early 20th century, particularly during the economic crises. And it was frequently "reactivated" in public discourses as a societal problem in the decades that followed, particularly in times of crisis (Weber 2014). However, a significant intensification of the debate and the emergence of civil society initiatives and campaigns[3] [4] against obsolescence is particularly noticeable since 2011. This intensification coincides with the release of the documentary "The Lightbulb Conspiracy" by Cosima Dannoritzer[4] in 2011, which shows some historical and current cases of an active reduction of the lifetime of consumer goods or at least the active acceleration of a new purchase. The documentary film points in particular to the agency of the manufacturers and the trade and as the "planners" of obsolescence. A perspective that has prevailed in media discourses.

Our content evaluation of about 200 contributions from online archives of regional and national newspapers on themes such as a "useful life/ lifetimes of consumer goods" or "obsolescence" since 2000[5] , shows that the obsolescence of consumer objects is mainly seen as a deliberate consequence of the malicious intentions of manufacturers in the vast majority of texts. Many media contributions start with a presentation of planned obsolescence as a common everyday experience of consumers by introducing the issue with a sentence like "Like all of us have already experienced: The electric toothbrush / printer / mixer stops working as soon as the warranty has expired…".

This perspective is underpinned in the media presentations by repeatedly referring to the same examples. This includes cases like so-called “light bulbs cartel”, which was formed in the 1930s by the world's largest light bulb manufacturers and which ended in agreements to standardise – and at the same time reduce – the burning time of light bulbs[6]. Another example, which also is a main case in the above-mentioned documentary, is the case of inkjet printers with smart chips in their ink cartridges that prevents them from being used after a certain threshold (number of pages, time, etc.), even though the cartridge may still contain usable ink or could be refilled. Further revenants are electric toothbrushes with glued-in rechargeable batteries or hand-held mixers with fast-wearing plastic wheels. Among these examples are cases like the light bulb cartel, that are vastly researched and relatively unequivocal, but for many cases the burden of proof is more on anecdotes rather than on scientific sources and long-term comprehensive studies. The anecdotal evidence provides no proof, but a presumed proximity to the lifeworld of readers. Furthermore, through the clear victim vs. perpetrator categories the reader can feel as a potential victim of fraud. The "perpetrator-victim narrative" is also relatively resistant to the results of various investigations that have so far provided no clear or comprehensive evidence for a system of maliciously planned obsolescence[7] and sometimes even report rather increasing use- and lifetimes (Oguchi 2017, Trentmann 2017). Although in the course of the publication of results such as the studies of the German Environmental Agency in 2015 and 2016 (see Prakash et al., 2016), several contributions that call into question the generalized charges against manufacturers emerged. However, recent developments in the context of various lawsuits against manufacturers, in particular those based on law on “obsolescence programme” in France, have again led to a significant increase in contributions that view the guile of (many) manufacturers as certainty.

It is not surprising that media reports often use simplified representations and categorizations to create a gripping narrative. However, these narratives do not remain ineffective and become problematic when they lead to a distorted perception that tends to exacerbate the denounced problem, as discussed below.

5. Perceptions and experiences of obsolescence - results of consumer research

The medial representation of the causes of short-lived products can affect the perception of the consumers' own role in the productions of obsolescence and their perceived options for action . Different surveys of consumer perceptions show that mainly manufacturers are held responsible for the longevity of products[8]. Consumers even seem to expect that their products will be shorter due to deliberate misconstructions and cite this as justification for their short usage time (Wieser et al 2015). Our own survey shows that 90% of respondents believe that some manufacturers purposefully built their devices in a way that they break shortly after the end of the warranty period of two years. Far more than half believe that it does not matter how much they spend on electrical appliances, since everything breaks down early anyway. However, when asked if they have ever experienced that an owned device has broken prematurely, more than 60% of the survey respondents denied. That is, the belief in planned obsolescence or the deliberate reduction in the lifetime by manufacturer affects the expectations towards products negatively, although the own experience provides no prove for that (see. Figure 2).

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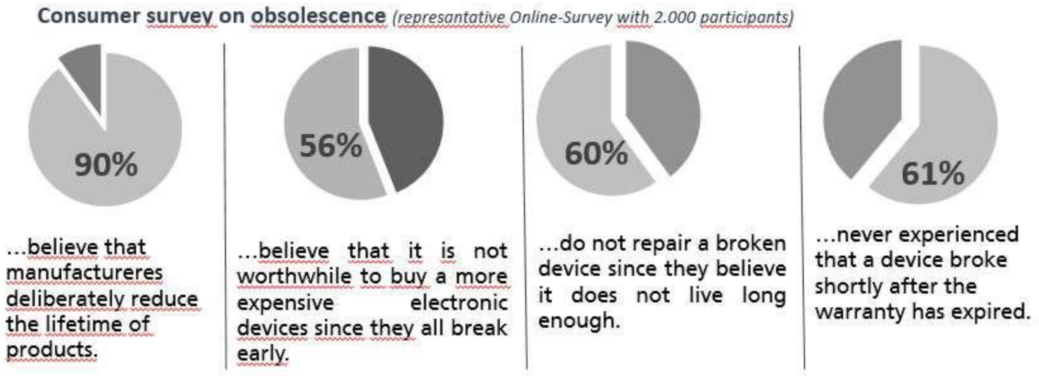
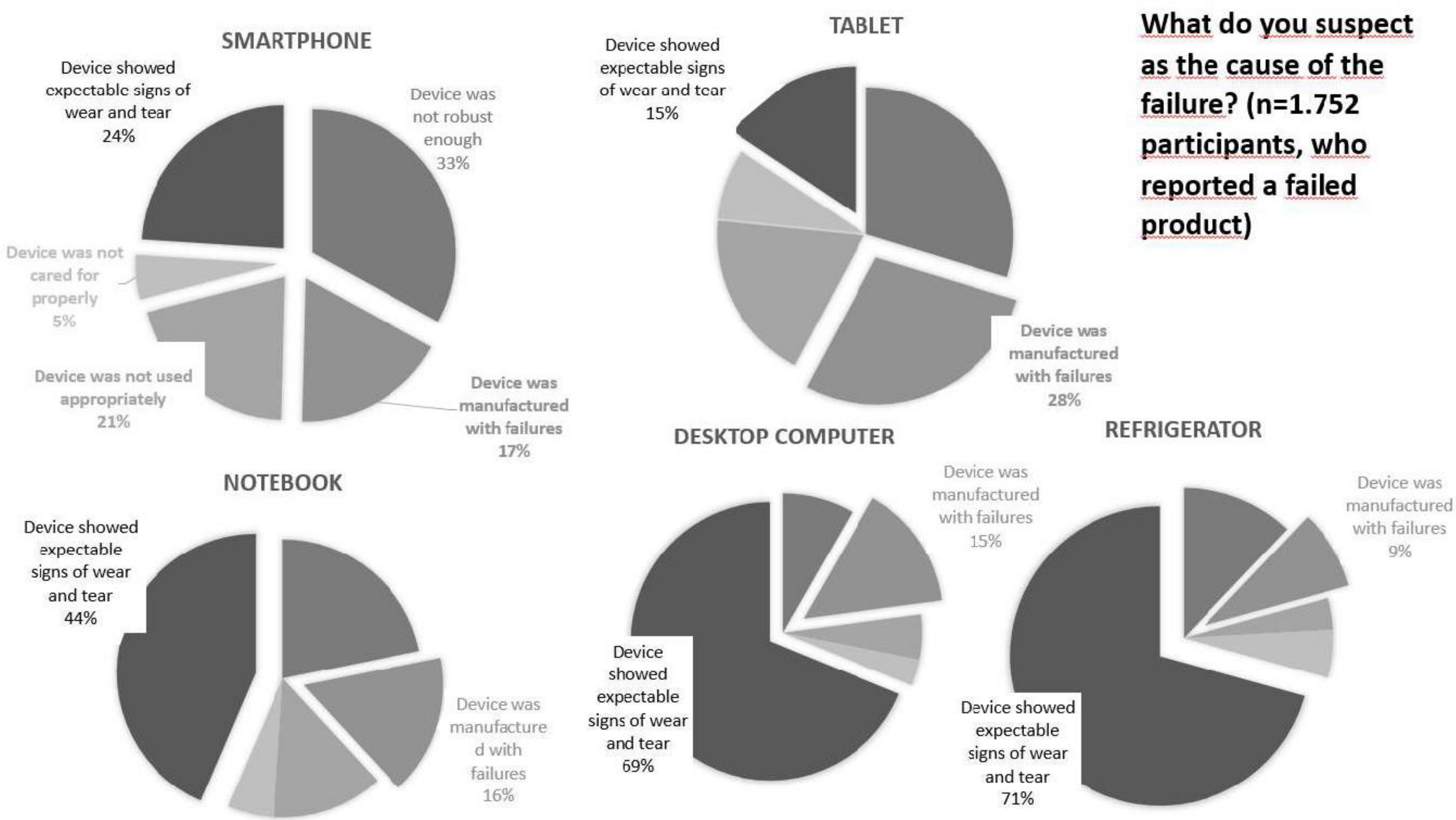


Figure 2: Communicative and material obsolescence in the perception and experience of consumers

The survey also asked about the respondents' experiences with broken devices and the presumed causes for their breakdown. When asked why the last device has reached the end of its lifecycle from the point of view of respondents, the main cause was that they failed due to expected signs of wear and tear (except for smartphones and notebooks) (see Figure 3)



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Thus, the representation in the media does not seem to be an all too common experience. - From the experiences of the survey participants, most devices reach the end of their life in a rather expected way because of anticipated wear and tear. Smartphones and notebooks are an exception, sine in most cases respondents suspect a lack of robustness. Both devices are among the most frequently used, mobile devices that are exposed to many potential threads, like falling down. This might be the reason why the proportion of devices that have broken down due to improper use is comparatively high In line with the interactive relationship between design and usage described above, it is also important to investigate how the usage practices affect the functionality of products. The frequency of care practices or maintenance of washing machines, like decalcifying the machine or cleaning the drawer, can affect its durability. Moreover, the routines of mobile phone charging affects the long-term performance and functionality of the battery. These actions are embedded in everyday practices, which are uch of it is automated and based on an implicit, practical knowledge. The decisive factor is whether the relevant knowledge for functionality and longevity exists. However, the knowhow often seems to be limited. Amont the survey participants, only about 40
% knew how a lithium-ion battery should normally be recharged so that its performance is maintained for as long as possible (Jaeger-Erben & Hipp 2017).

Another important question is whether enough time and space for care and maintenance is available in everyday life. Our survey points out that the proportion of people who do not care for or maintain their devices properly for lack of time is about one third. Thirteen percent do not fix a broken device and immediately buy a new one since they cannot do without the device. Successful conduct of everyday life seems to be based on the fact that devices are functional and available. At the same time, everyday life does not leave enough room for maneuver to ensure long-term functionality of the devices. This observation adds an alternative perspective to the common assumption that an early new purchase is primarily related to the "allure of the new" and a high sense of fashion or status (Ullrich 2014, Klose 2015, Harrell and McConocha 1992). Nevertheless, various studies show that there is a considerable number of people preferring new products to caring for the old ones because they want to "go with fashion" (Cox et al., 2013). In our survey we also found that about one fifth of the participants see a broken device as a welcomed opportunity to buy something new. They relate quality of life to new devices and are happy to show that in their social environment.

To explore further on the role of newness, we analysed the relation between the attractiveness of newness and the usage time of the last device by applying a multiple regression in SPSS. Previously, an explorative factor analysis was conducted determining attitudinal factors concerning novelty, perception of responsibility, (dis)satisfaction with the status quo, etc. The self-reported realized use time (material practice) of the previous electronic device was assessed by asking how many months the previous smartphone had been used, and how many years the previous washing machine had been used. The attractiveness of newness was extracted from an exploratory factor analysis and bases on seven items (α=.85), e.g. Having new devices means quality of life to me". Other factors were: Responsibility for longevity attributed to the producer (10 items, α =.85, e.g. 'Producers of electronic devices should pay more attention to longevity when designing products.') and to the user (6 items, α =.74, e.g. 'consumers should be more careful with their products so they last longer.'); satisfaction with the status quo of product longevity in society (2 items; e.g. 'I am satisfied with my rights as a consumer.'); indifference about product longevity (2 items; e.g. 'I don't have time to maintain devices.'); and the purchase criterion of longevity

(2; e.g. 'I buy devices that are more expensive but last longer. These attitudinal factors were entered in multiple regressions with the usage time of the last washing machine or smartphone. The analyses revealed that the length of the usage time of both devices negatively predicted by the attractiveness of newness, whereas the other factors were not linked to the use phase, except for the felt user responsibility, which positively predicted the usage time of the smartphone. That means that attractiveness of newness is the best predictor of how long a device is used (compare also Frick et al. 2019).

However, fashion, status and novelty value are only drivers of obsolescence depending on the cultural context, and this context explains why there are differences between product categories. For example, it is often more important to own and demonstrate the latest fashion in case of mobile phones but not in the case of large household appliances (Wieser et al 2015, Evans and Cooper 2010, Cox et al 2013, Cooper and Mayers 2000). In our survey, the proportion of respondents who bought their current device, even though the old device is still working, is also significantly higher in the case of smartphones (around 60%) than in washing machines (44%). And in this regard, it is worth taking a look at how the device is embedded in everyday practice. The smartphone as a "digital life companion" (Eisentraut 2016) has an important role in the design of everyday life and social relationships and is constantly visible to the social environment. Devices that stand in the kitchen or cellar and above all have mainly one function, such as "washing" or "cooling", play an entirely different role in everyday life . The novelty thus serves only partly as an explanation, therefore a more thorough analysis of social practice in dealing with different devices and the different forms of everyday integration is necessary. This consideration, in turn, needs to be embedded in the structural incentives and opportunities that favor a new purchase over function preservation and long-term use. Buying a new device seems much easier to many consumers than repair and is stimulated by appropriate offers. Not least the digitization and the simplicity of online shopping contribute to the impression that everything is easy and simply available and that resources or material are worth nothing and therefore not worth preserving (Hilty 2017). In addition, care, maintenance and repair are structurally not only neglected, but sometimes even prevented. For example, the design - bonded parts, miniaturization and modularization - can make repairs and care practices much more difficult. When selling, information about the technical function (capabilities) and maintenance requirements are not in the foreground and consumers often feel a kind of learned helplessness in dealing with technically predictable devices (Echegaray 2016) .

Function and visibility of the device e in everyday life, time and expertise to care, maintenance and repair and the product-related and structural incentives and barriers to the preservation of the old and the acquisition of the new therefore affect the freedom of action of consumers. The high dependency on functioning devices and the dense timing of everyday life complicate life-prolonging actions and accelerate the functional obsolescence.

In addition, the consumers' influence on product lifetimes are perceived as limited by the survey respondents, which corresponds to a low feeling of responsibility for functionality and durability. If the common media presentation is believed, the own possibilities - and thus the willingness to accept responsibility - are regarded as very limited, because "the market" controls the lifetime. The expected (short) lifetime can have a significant influence on the length of the realized useful life and on the date of replacement (Cox et al. 2013 , Wieser et al. 2015). In our survey, one-third of reported broken devices were not repaired because the assumption was that a repair would not be worthwhile because the device will not last long enough.

However, not all responsibility attributions point towards the manufacturer. As indicated above, the vast

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majority (94%) agree with the statement that "we live in a throw-away society". About eighty percent find it "awful that fellow citizens buy new electrical appliances, even though their old ones still work" and just as many believe that the advertising significantly influences the needs and encourages new purchases. Thus, the survey reflects somehow the cultural pessimism that also characterizes the media presentations of today's consumer society. Thus, a crucial question is: Who can bear the responsibility for the product if the actors themselves do not have any room for decision and action?

6. Factors influencing life span from a holistic perspective

The preceding sections presented some empirical insight into the communicative and material reproduction of obsolescence. The insights into the discourse on obsolescence bear witness to a communication that works primarily with simplistic categories and linear attributions of cause and effect, often with the aim to tell an interesting story. This story draws some one-dimensional pictures of both, the manufacturer or product designer and the consumer. However, it also reveals a very limited view on the products.
Firstly, practical action by manufacturers and consumers are limited to decisions (for a particular design / business model for new purchase / discarding) and the decision itself is mainly presented as based on cost-benefit considerations. Manufacturers and consumers alike are said to make more or less calculated decisions for their own benefit maximization - be it benefits through financial gain and competitive advantages or by status and novelty consumption. The practice itself and the relevant, often limited know-how or the structural, often unquestioned logic, which offer incentives for the one and hinders other actions, remain underexposed.
On the other hand, the products themselves attract little attention and appear rather as "passive puppets". They only become conspicuous when they can be presented as novelty, when they no longer function or when they become threatening as "electronic waste mountains". Otherwise, being defined as passive, the objects can be used by companies to project their profit dreams onto them or by consumers to satisfy the desire for the new. To put it bluntly, producers and consumers are somehow accomplices in the production of obsolescence and the consumer products are the actual victims - and with them the natural resources used for that purpose, as well as the people and environments that are affected by manufacturing and disposal practices.
This escalation may initially be irritating: What should a consumer product be other than a human-made and manipulated object? Here we return to the triangular relationship of design, usage and object outlined above and add an extended understanding of consumer objects as "equal playing partners" (Miller 2006)) or "teammates in social practice" (Hörning 2016). As a co-player, consumer objects can be resistant and inscrutable; they can refuse their "service" and interrupt the flow of practice. This is all the more true for modern electronic products and digital, mobile technologies, which are becoming more and more important actors and role carriers in everyday life through an ever-expanding "life of their own" (Rammert 2009, Rammert , Schulz-Schaeffer 2002). Furthermore, modern production processes are complex chains and networks of globally widely distributed practices. It becomes an almost impossible challenge for product developers and manufacturers to keep an eye on all the components and functions - and thus possible malfunctions of the devices. Samsung's effort to understand why the Galaxy Note 7 batteries exploded shows that even market leaders have limited access and limited
knowledge of the features of their device components. The emergence of a product and its quality involves a large number of actors who act according to their own logics. While designers primarily focus on the product

itself, controlling and trading are above all interested in an increase in margins, which is the practice-relevant logic. In addition, not only does everyday life seem to accelerate, product developers also have less and less time to plan the quality and reliability of their products.

However, this independent role of consumer products usually only becomes the focus of attention when they do not work (van Hinte 1997). The controllability and functionality is taken for granted, without thinking about how elementary it is for the design and use in everyday life. The acceleration of everyday life by both product developers and users, the increasing complexity of manufacturing processes and devices, and the resulting decrease in know-how are the real challenges in the case of obsolescence.

As long as short lifetimes and usages times and the selling or purchase of new items is structurally more supported than prolonging the life of the old, by repair, reuse or upcycling, premature obsolescence will be reproduced. In our survey robustness and long durability were nominally declared to be the most important criteria in the selection of a device. At the same time in many cases a new - as robust as possible - device is purchased, although the old device just proves its long robustness and durability and still works. These kind of paradoxies cannot be understood by applying a linear cause and effect or attitude-behaviour-scheme. Our final plea is therefore that the focus of consideration must be more on the generation of system knowledge. In order to develop options for action and transformation paths, it is important to decipher the "culture of obsolescence". In other words: When looking for the causes of short-lived electronic products and fast-moving consumption, we do not construct a detective story with clear perpetrator-victim categories, but - as in an archaeological excavation - expose the fabric and layers of our material culture and ask ourselves the open question why the short life of consumer products can be useful, practical or simply the easiest way for different social actors. Only a systemic understanding of the causes, drivers and stabilizers of obsolescence allows to effectively answering the question of who is in which way responsible for the lifetime of consumer products.

Endnotes

3 The research presented here is part of the research group “Challenge Obsolescence” (challengeobsolescence.info) funded 2016 – 2021 by the German Federal Ministry of Research and Education/Social Ecological Research Programme (www.bmbf.de/en/socialecologicalresearchfunded by the BMBF since July 2016

4 The online survey took place in 2017, with recruitment over a panel institution and coupon reimbursement for participation. Participants were invited via the institution’s platform and the sample was curated by screen-out conditions so that representativeness for the German population for age, education, income and gender was given. The sample consisted of 2.000 participants between 14 and 66 years of age.

5 An example is the French NGO “HOP – Halte à l’obsolescence programme” or the German organisation Murks NeinDanke eV

6 https://www.videoproject.com/Light-Bulb-Conspiracy-The.html

7 The research based on terms such as obsolescence, lifespan, and product life. The body contains articles from 28 daily and weekly newspapers. The analysis of the articles was oriented towards the approach of

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discourse analysis (Keller 2011). It is a qualitative-reconstructive method that is often used in the analysis of media to work out how social order and social meanings are constructed and constituted in discourses. The following are some initial results of the ongoing analyzes reported.

8 While it is for the arrangements of the light bulb manufacturers to limit the burning time of incandescent lamps to about 1 . 000 hours documents are , it is debatable whether this is a conscious, sales increasing deception of consumers * inside or an agreement to standardize the quality of light concerned (Krajewksi 2014) . The central parameters for a light bulb life, light output and power consumption can each be optimized only to the detriment of the other parameters. For example, a more durable bulb will emit less light while consuming the same amount of power, so the desire for brighter bulbs will inevitably affect their burn time. For example, the light output of Centennial Bulb, which has been in operation for over 100 years (see footnote 9), is only 4 watts.

9 See, for example, studies by the Öko-Institut on behalf of the Federal Environment Agency or the project LOiPE and Wieser et al 2015

10 European Economic and Social Committee: How do lifecycle information affect the consumer ?, Brussels 2016

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