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What Are the Obstacles, Drivers and Future Way Forward?
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Enhancing policies for deployment of Industrial symbiosis
– What are the obstacles, drivers and future way forward?

Rikke Lybæk*, Thomas Budde Christensen, Tobias Pape Thomsen

Department of Environment, Technology and Social Studies (TekSam), Institute of People and Technology (IPT), University of Roskilde, Universitetsvej 1, House 9.2. P.O. Box 260, 4000 Roskilde, Denmark. *E-mail: rbl@ruc.dk (R. Lybæk), tbc@ruc.dk (T. B. Christensen), tpapet@ruc.dk (T. P. Thomsen).

Abstract
This paper contains an analysis of Industrial symbiosis policies to explore how development Industrial symbiosis systems is influenced by policies and to examine how future policy frameworks can designed to best support the development of Industrial symbiosis systems. Industrial symbiosis is in the paper defined as the connection of traditionally separate industries in a collective effort to simultaneously increase competitive advantage and reduce environmental impacts by means of byproduct exchange and shared infrastructure. The paper is based on three components: First, the paper reviews, journal articles to provide a policy landscape overview of how such Industrial symbiosis systems are supported by policies and in which areas new policy needs can be identified. Secondly, the paper reviews and discusses policies and framework conditions, provided by the European Union (EU), the United Nations (UN) and the Organization for Economic Cooperation and Development (OECD) designed to support the development of Industrial symbiosis systems. The analysis distinguishes between direct and indirect policies in order to emphasize that the development of Industrial symbiosis systems is influenced not only by policies directly targeting industrial symbiosis but also by general framework conditions that may not have been designed with Industrials symbiosis in mind. To improve the understanding of such in direct policies the paper thirdly includes a case study from Denmark, Maabjerg Energy Center (MEC). This case provides new insights into the application of Industrial symbiosis concepts, especially with regards to how framework conditions and indirect policies can influence and shape the development of industrial symbiosis systems. Based on these three components, this paper analyses obstacles and drivers for a further dissemination of Industrial symbiosis within the EU, and suggest key points for further assessment and development on a potential way forward. From the literature review and framework conditions assessed, general recommendations are provided whereof many relate to the potential benefits of focusing more on development and re-development of indirect incentive schemes fostering symbiotic behavior in industries as opposed to focusing only on designing policies exclusively based on direct top-down regulations. From the case analysis, several examples of more context-specific drivers and obstacles were highlighted as valuable in the given situation including the potential benefit of more flexible funding schemes, the importance of positive value-based communication to gain political support on the local, regional and national environment, feed-in tariffs and tax reliefs and the relevance of having centralized legal organs with specialized competencies on regional or national level to support development and implementation efforts.

Keywords: Case study, Framework conditions, Industrial Symbiosis, Maabjerg BioEnergy, Policy review.
Introduction

The word *symbiosis*, means interaction between organisms and the concept is commonly used in biology to describe interdependencies between species in eco-systems. The concept of symbiosis is however also applied on industrial systems, where companies exchange waste and by-products in order to reduce their collective amount of resource usage. The concept of symbiosis is thus used as an analogue to biological systems, where symbiotic relations between companies refer to interdependencies created from the exchange of by-products and/or shared infrastructure. The use of the industrial symbiosis metaphor in academic literature on industrial organization, origin in the *industrial ecology* concept, developed in the late 1980s (Frosch and Gallopoulos, 1989). By creating such systems, environmental- and resource related problems are sought dealt with, while at the same time improving the economy for companies involved in such material- and energy exchanges.

Research indicate that development of Industrial symbiosis partnerships has the potential to close material loops, reduce energy usage and thereby provide a more circular economic model for modern companies (Jelenski et. al., 1991; Gertler, 1995).

Different types of Industrial symbiotic systems exist including; i) ‘classic’ inter-firm connection between companies, located close to each other within a defined area, ii) inter-firm network of companies located within the same region with symbiotic relations, and iii) inter-firm collaboration between companies across longer distances (Chertow, 2007). According to Albino et. al. (2016) and Chertow (2007), at least three different companies must inter-connect and work together, in exchanging at least two different resources, before the companies can be recognized as part of an Industrial symbiosis.

The overall raison d’être of Industrial symbiosis is for companies to simultaneously achieve cost reductions and environmental benefits, by using by-products and wastes generated by one company, as raw material inputs for another company. Besides this, Industrial symbiosis may also involve sharing of infrastructures such as buildings and facilities, energy and water supply and various other types of resources (Petrikova et. al., 2016). The difference between *Industrial symbiosis* and *Industrial ecology* is that the latter seek to establish sustainable closed-loop systems through a combination of industrial eco-systems, industrial symbiosis, industrial metabolism and environmental legislation and regulations. Industrial symbiosis is hence a means and subset to reach this, by its emphasis on e.g. energy and waste exchanges to create synergies, and hence to be able to reach the overall goals of ‘industrial ecology’ (Li, 2018).

Over the last ten years, the concept of circular economy has gained increasing popularity in policy and academia. Circular economy covers many of the same aspects as industrial ecology and Industrial symbiosis and organizations like the Ellen MacArthur Foundation has successfully managed to revitalize years of accumulated knowledge and convey this knowledge to policymakers in policy and businesses under the umbrella concept circular economy (Ellen MacArthur Foundation 2013). A review by Ghisellini et al. (2016) places Industrial symbiosis as a key component of the circular economy literature. However, a clear difference between the two concepts is that the literature on Industrial symbiosis focus (almost) exclusively on the production side, whereas circular economy covers the full circle from resource extraction, over production to consumption and back into new products, thereby making Industrial symbiosis a subcategory under circular economy.

To support development and enactment of the Industrial symbiosis concept, numerous policies have been proposed and implemented by governments across the globe. On the supra-national level, Industrial symbiosis has found support as a development initiative within the circular economy,
materialized through legal frameworks in the European Union (EU) and the United Nations (UN). However, it is no simple task to develop generalized policies to support development of industrial symbiosis systems as these are complex socio-ecological constructions and no two are exactly alike.

To improve the knowledge based for policy development in this area, several academic studies have been published in recent years (Shi et. al., 2010; Costa et. al., 2010; Behera et. al., 2012) to present case studies on policies targeting development of industrial symbiosis initiatives and evaluate the success hereof. Usually, the academic focus has been mainly on efforts that directly articulate and support the implementation of Industrial symbiosis and such political initiatives are often regarded as pivotal for a further development. Less focus, has been given to the abundant array of policies which may not directly aim at supporting development of industrial symbiosis - but which - nonetheless, can have a massive impact on the success and failure hereof (Lehtoranta et. al., 2011; Shi et. al., 2010). Another largely overlooked theme of the industrial symbiosis developments is that of the failed cases. While recent research on industrial symbiosis is generally rich in practical examples and case studies of successful symbiosis establishment and operation (e.g. Branson 2013; Martin and Eklund 2011, Sokka et al 2011; Yang and Feng 2008; Mirata and Emtairah 2005), only limited attention is usually given to the study of how and why some emerging industrial systems fail and in accordance hereof identify how policy influence success and failure of such emerging systems.

This study aim to support future policy development processes within the area of industrial symbiosis by shedding new light on a less studied part of the policy landscape - namely that of more indirect policies appropriate for supporting Industrial symbiosis, and how this may relate to the more direct policy initiatives. Based on an approach that combines a literature review of European policy frameworks with a new case study of an industrial symbiosis system that has succeeded as well as failed, the paper deduct valuable learnings to define a potential way forward for development of future industrial symbiosis policies.

2. Research methodology

2.1 Exploratory literature review

The methodology for the literature review is based on a two-step approach combining an exploratory review and snowball technique. In our exploratory literature review (see for example Lazona et. al., 2015; Hoppe et. al., 2016; Schiederig et. al., 2012) journal articles from year 2007 to 2020 were - firstly - identified by using the keywords Industrial symbiosis, circular economy and policy on the journal search engines Scopus and Science Direct. Only high-ranking journal articles including these keywords were selected for further review, as for example Journal of Cleaner Production, Journal of Industrial Ecology, Sustainable Development and Environmental Science and Technology.

Secondly, we applied a snowballing technique (Greenhalgh and Peacock, 2005; D’Ippolito, 2014) to identify key studies, focusing on policy programs that both 1) investigate a specific single policy program, 2) evaluate its success in facilitating deployment of Industrial symbiosis, 3) compare different policy programs or investigate the evolution of policy programs. This implied a thorough scanning of the reference list of all high-ranking full papers, and consequently a selection of new papers to study as having a core policy focus.

Using this method helped us to identify journal articles that review Industrial symbiosis research, in a broad sense, as for example Huang et. al. (2019), as well as more specific policy review articles on
Industrial symbiosis, as provided by e.g. Jiao and Boons (2014) and Tao et al. (2019). Thus, the exploratory approach combined with the snowballing techniques applied in this paper, have been utilized to identify the state-of-the-art of Industrial symbiosis policy research. The aim has therefore not been to provide a full systematic literature review or policy analysis, but to extract key tendencies of the nature of the policy landscape supporting the deployment of Industrial symbiosis. The applied approach has previously been used by scholars within both social science and more transdisciplinary research fields, revealing trends in e.g. company business models, how sustainable development is integrated in higher education, and how policy studies are being utilized within energy research (D’Ippolito, 2014; Lazano et al., 2015 and Hoppe et al., 2016). The snowballing technique can be utilized as a pre-study to define and shape further analysis, or to collect detailed knowledge for research purposes, as in our case.

To supplement data retrieval from journal articles, we have also accessed; i) OECD reports with emphasis on deploying Industrial symbiosis, ii) European policy frameworks, iii) UN policy frameworks and iv) publications from dedicated Industrial Symbiosis organizations as e.g. the Nordregio report 2015. The aim of these activities has been to map current direct policy (see below) initiatives for supporting Industrial symbiosis on the supra-national governmental level as well as identify the most recent and relevant recommendations – from the private organizational level, related to potential supportive activities in promoting the deployment of Industrial symbiosis.

2.2 Case study

The Maabjerg Energy Center (MEC) in Denmark is an Industrial symbiosis application, which revolves around renewable energy production, agriculture and waste utilization. The MEC case is selected for two main reasons. Firstly, because it is a relatively large and quite new system that is only sparingly described in scientific literature on Industrial Symbiosis and related policy, and secondly, because the development of this symbiosis system has a first phase that succeeded and a second phase that did not. This increase the possibility to identify relevant policy drivers as well as barriers from the case development.

Data for the case study is based on qualitative interviews with the Chief consultant at Vestforsyning (one of the owners of Maabjerg Bioenergy Center), plant visits and a document analysis. From this case study, data retrieval is conducted mainly concerning the more indirect policy landscape (see below) for supporting Industrial symbiosis.

2.3 Policy focus and analysis

In our analysis, we distinguish between top-down and bottom up-policies. Top-down policies we understand as policies formulated by e.g. central governments and the EU, whereas bottom-up policies are understood as more local incentives, support and initiatives, etc. taken by local stakeholders and governments at the municipal and regional level. We also distinguish between direct and indirect policy programs and framework conditions. “Direct policies” we define as policies formulated by a governmental agency (on national, regional or local level of governance) that are designed explicitly to support, promote or legally enforce industrial symbiosis and “indirect policies” are defined as policies that are not explicitly designed for industrial symbiosis but influence industrial symbiosis systems anyway. The indirect policies cover a very broad spectrum of general framework conditions such as infrastructure policies, general tax and tariff policies, waste policies and general policies that regulate market conditions for resources, products or services etc. which share the common feature that they unintentionally influence industrial symbiosis systems. The market
requirements in the EU for second-generation biofuels can be seen as an example of an indirect policy as they are designed to support the implementation of the renewable energy directive but indirectly have a major influence on industrial symbiosis systems linked to bio-refineries as described later in the assessment of the MEC case.

Framework conditions are broadly understood, as the overall research support, policies and formulated goals etc. Both (direct) policy programs and indirect policies can influence creation of industrial symbiosis systems, through for example policies and regulations. From the data retrieval described above important issues of relevance for further policy suggestions connected to the deployment of Industrial symbiosis are identified (policy needs), which are elaborated further in this paper, with a goal of providing new policy suggestions (drivers) and a way forward for adopting Industrial symbiosis within society.

3. Findings from the literature review

In the following section, we divide the findings from the literature review into Policy programs, Mechanisms to support Industrial symbiosis, Impact of policy programs and Lessons learned to provide a deeper analysis of each element. Highlight summaries of the main findings of the literature review and the policy assessment are provided in Table 1 and 2.

3.1 Journal articles

Policy programs: Several articles like Geng et al., (2012) and Behera et al. (2012) evaluates single policy programs, which emphasize the success of one single policy initiative. Geng et al., (2012) e.g. explores the indicator systems guiding the implementation and evaluation of circular economic (CE) initiatives in China, questioning its impact on economic performance, environmental quality and hence contributions to sustainable development. Lack of mandatory use of the indicators by companies, as well as lack of common goals for Industrial symbiosis initiatives, is hence being problematized (Geng et al., 2012). Another aspect that can be found in research emphasizing single policy programs is network development. Here, the importance of appropriate policy instruments, capable of transforming traditional industrial complexes into Eco Industrial Parks is, for example emphasized by Behera et al. (2012).

Research comparing several policy programs emphasize how various policies are adopted in different contexts. Costa et al. (2010) have e.g. investigated how supra-national, national and sub-national Industrial symbiosis governance has been applied in the UK, Denmark, Portugal and Switzerland, as supportive waste management policies. The research indicates that defining clear government policies supporting companies, while at the same time allowing flexibility at the local implementing level, is highly important. Zhang et al. (2010) analyze two national Chinese policy programs supporting Eco Industrial Parks and conclude, that there is a need for more coherent policies, better coordination between programs and better supervision in supporting the development of Industrial symbiosis. Eco Industrial Parks have been the focus of several other studies to facilitate circular economy initiatives e.g. (Huang et al., 2019).

Research with focus on the evolution of policy programs addresses the development of certain policies over time. This could include e.g. green growth, innovation, eco-efficiency etc., and European policy targeting Industrial symbiosis initiatives. Here, lack of appropriate policies bridging and creating synergies between these are identified, as emphasized by Laybourn and Lombardi (2012). The evolutionary perspective is the focus of Mathews and Tan’s (2011) study, in which they
compare the development of Chinese Eco-Industrial Parks with other such parks from around the world. They find it vital that governments are present and provide support in the initial stage of Eco-Industrial Park planning. In the evolutionary research of Industrial symbiosis in general, it has often been a focus to understand and increase the resilience (stability) of Industrial symbiosis to decrease their vulnerability (Huang et al., 2019).

**Mechanisms to support Industrial symbiosis:** The inherent need for research into policies that stimulates the creation of Industrial symbiosis and the related governance strategies and supporting mechanisms has been emphasized (Salmi et al., 2011; Shi et al., 2010).

**Research on stimulation of Industrial symbiosis development** evaluate the need for financial, operational and legislative support to promote Eco-Industrial Parks. Salmi, et al. (2011) find that barriers for implementation can be rooted in the current market-based regulatory system. Ohnishi et al. (2012) find that policy intervention is crucial for the deployment of re-cycling projects and thus the creation of Industrial symbiosis initiatives and the number of re-cycling projects are far too low, primarily due to unfavorable or absent subsidy policy. However, according to Huang et al. (2019) many policy researcher find in their studies that public policies have supported and promoted the emergence of self-organized Industrial symbiosis, as is the case for example for Chertow (2007) as described below.

**Governance strategies** looks at the policy instruments and subsidies being provided by governments. Shi et al. (2010) finds these appropriate in a Chinese context, through the support to cleaner production, waste management and Industrial symbiosis within industrial areas. The authors however call for public policies that adjust incentive structures for industrial “symbiosis activities”, by economically recognizing positive environmental results obtained by companies, rather than only focusing on establishing Industrial symbiosis exchanges. Other studies focus on the lack of legislation and appropriate governance by officials in guiding companies in their management of waste streams, and stress that better coordination mechanisms between companies could motivate them to develop profitable new ways of using their waste stream (Brent et al., 2008).

Research on **mechanisms that favor Industrial symbiosis** investigates the underlying reasons for why Industrial symbiosis emerges. Chertow (2007), for example, stress the reasons being embedded in economic, social, environmental and regulatory reasons. She points to the self-organization and planning between networks of companies, as motivation for implementing cooperation by means of Industrial symbiosis initiatives. Social network analysis (SNA) has widely been utilized to research such network of companies, identifying symbiotic linkages and organization between industries, hereunder trust (Huang et al., 2019).

Other studies - e.g. Boons and Spekkink (2012), conclude that institutional capacity is the underlying reason and stress that more emphasis should be given to building up such capacity within companies for them to act. They argue that certain social conditions must be in place before symbiotic relations will emerge. Elaborated further by Simpson (2012), it is found, that companies often do not know how to act on the environmental scene, which makes them respond negatively to re-cycling pressure, as they have inadequate knowledge to comply with requirements.

**Impact of policy programs:** Research on policy programs and their implications, has often applied case studies, as a tool to investigate situated cooperation between companies by means of various symbiotic relations (Huang et al., 2019). Similarly, cases can be used in quantitative examinations of policy impact analyzing environmental and economic performances of symbiotic relations, between symbiotic companies (Jiao and Boons, 2014). Different policy support programs have different impact on the materialization of specific Industrial symbiosis due to varying effect of subsidies and legislative conditions as emphasized by Van Berkel (2009).
Also, EU policy support schemes have been investigated, where for example Lehtoranta et. al. (2011) find - from the analysis of a Finnish pulp and paper factory - that indirect encouragement by national and local governments to develop materials and energy exchanges, are more favorable than direct top-down obligations posed on them by the EU. It is thus concluded that incentives-based policy support at the local level regarding land-use regulation and planning are important for Industrial symbiosis to develop, and that e.g. indirect waste policies are more valuable for industries that direct policies targeting Industrial symbiosis (Ibid.). This is in line with Kim (2007) who finds that governments should focus on local incentives rather than top-down regulation, based on the results from company interviews with various stakeholders from the industry within the Macheon Industrial Park in South Korea.

Lessons learned: Case studies have, as seen above, been utilized to reveal the successes and failures of programs focusing on policy implications and lessons learned (Jiao and Boons, 2014). As indicated by Lehtoranta et. al. (2011) and Kim (2007), the main lessons on policy implications is to avoid strict top-down regulation only, but to more strongly focus on incentives-policy at the local level when supporting Industrial symbiosis. Adamides and Mouzakitis (2009) further suggest adopting strategic niche management (SNM) as a tool to facilitate the transition to a more symbiotic society, and stress that the goal of a symbiotic society, should be integrated in national and regional technology policies, and thus have overall policy implication for the future.

3.2 Policy frameworks for Industrial symbiosis

This section provides an overview of the most important political frameworks and initiatives addressing Industrial symbiosis in the European Union (EU) and the United Nations (UN).

EU policy: Within the EU, Industrial symbiosis developments has been highly recognized as a tool to achieve a more circular economy (Mortensen and Kørnøv, 2019), to obtain green growth and more efficient business inter-actions across different value chains (EC, 2018), and to disseminate new business models and strengthen the market for re-cycling of by-products, hereunder to deploy more sustainable means of manufacturing within European businesses in general (EC, 2014).

In the ‘Resource Efficiency Europe’ flagship initiative of the ‘Europe 2020’ strategy the EU, recognized the potential contribution of Industrial symbiosis to sustainable consumption and European industrial competitiveness. A part of the ‘Resource Efficiency Europe’ flagship is the ‘Roadmap to Resource Efficient Europe’ (EC, 2011), which stress that by enhancing the re-use of raw materials through deployment of Industrial symbiosis it is achievable to save up to 1.4 billion Euro annually throughout Europe, and earn 1.6 billion Euro in product sales. The Roadmap hence encourages member states to help companies to cooperate in order to increase their use of waste energy and by-products, by means of Industrial symbiosis.

Also, ‘A stronger European industry for growth and economy recovery’ (EC, 2012), launched in 2012 as a Communication of the European Commission, foresees that future companies will adopt highly efficient resource manufacturing processes with focus on minimizing materials and energy usage.

In the Circular Economy Action Plan (EC, 2015), the EU encourages companies to innovate their production processes, including applying Industrial symbiosis initiatives. In the Action Plan the Commission is proposing to clarify rules on by-products to assist Europe in deploying a more systematic approach to eco-innovation and to facilitate innovation to develop cross-sectoral arenas’ and enhancing closed-loops activities.

Through the research and innovation program Horizon 2020, the EU also seeks to support the
development of ‘industrial symbiosis. This is specifically addressed in the program launched in 2014-2015, where two calls were initiated: ‘Leadership in enabling and industrial technologies’ and ‘Climate actions, environment, resource efficiency and raw materials. In the program launched in 2016-2017 the focus area e.g. ‘Cross-cutting-activities’ can provide funding for Industrial symbiosis research in the priority area of ‘Industry 2020 in the Circular Economy’.

**UN policy:** The UN (via UNEP) supports Industrial symbiosis with a focus on resource efficiency, circular economy and sustainable consumption and production (SCP), which is an integrated part of the organization’s development goals. Proposed drivers include redirection of investments, more sustainable technologies, better international and national co-operation (hereunder goal 17 of the UN’s SDG), capacity building, as well as the reshaping of national economies and the global economy. UN has promoted the development of Eco-Industrial Parks since the 1990s, with the optic of such collaborations being superior to other industrial systems by integrating economy, ecology and social dimensions (Lehtoranta et al., 2011).

The UN focus on the following four themes in their current work setting up instruments in supporting relevant schemes for the future: i) Strengthen and communicating the knowledge base for SCP and resource efficiency. ii) Capacity building within governments. iii) Consolidating and extending business and industry partnerships and iv) Influence consumers in their purchase choice. UN has provided an international policy framework for cooperation in creating resource efficiency, and has been a platform for international exchanges of knowledge between stakeholders and countries, etc. Besides this, UN has established an International Resource Panel (IRP) with experts working on resource efficiency, life cycle thinking and decoupling of economic growth from use of energy and material resources (IRP, 2014 & 2019).

**OECD policy:** The OECD has published numerous reports on Industrial symbiosis, which this organization regard as an important concept and a way forward in ‘doing more with less’ (OECD, 2011). They stress that Industrial symbiosis is a systemic innovation vital for future green growth (Ibid.). In the 2015 report ‘Materials Resources, Productivity and Environment’ they conclude, that a resource efficient economy is important for achieving green growth and that better policies are needed to support circular economic initiatives, hereunder Industrial symbiosis. The organization also argue that resource use should be improved through further use of sustainable natural resources and enhanced material management, which include reduce, reuse and recycle initiatives; the 3 R’s (OECD, 2015).

The OECD list the main obstacles to provide relevant policies that promotes sustainable development and circular economy, hereunder industrial symbiosis initiatives (OECD 2011 & 2015):

i) Greater coherence between policies dealing with resource utilization and materials management. This could be coherence between investment and trade policies and environmental policies, etc.

ii) Stronger partnerships between research and civil society and the private sector.

iii) Better understanding of the materials and energy flows through the national and international economies and their relation to productivity and environmental risks.

iv) Increase resource efficiency and shared policy principles to secure resource productivity and investment guidance.

v) Allow different solutions to be applied in different contexts and governance levels, agreed upon as shared international visions.
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<th>Review topic</th>
<th>Emphasis / findings of literature review</th>
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<tr>
<td><strong>Policy Program</strong></td>
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<tr>
<td>Single policy program</td>
<td>- Impact on economic &amp; environmental performance, and contribution to sustainable development (Geng et. al., 2012)</td>
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<td>- Effect of indicators used by industry to promote Industrial symbiosis (Geng et. al., 2012).</td>
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<td></td>
<td>- Success in network development between industries (Behera et al., 2012).</td>
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<td></td>
<td>- Capability to transform industrial complexes into synergetic parks (Behera, et. al., 2012)</td>
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<tr>
<td>Several policy programs</td>
<td>- Clear policies supporting companies in their effort to engage in Industrial symbiosis (Costa et. al., 2010).</td>
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<td></td>
<td>- Coherent policies with better administrative supervision (Zhang et. al., 2010).</td>
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<td>- Good coordination between different supportive programs (Huang et. al., 2019).</td>
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<td>Evolution of policy programs</td>
<td>- Bridging appropriate policies to enable synergies (Laybourn and Lombardi, 2012).</td>
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<td>- Governments to be present in the initial stage of activities to support the planning, etc. (Mathew and Tan, 2011).</td>
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<td>- Increase the resilience of industries having a synergetic relation, and thus (Huang et al., 2019).</td>
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<td>- Decrease the vulnerability of synergetic cooperation. (Huang et. al., 2019).</td>
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<td><strong>Mechanisms supporting industrial symbiosis</strong></td>
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<tr>
<td>Research on stimulating Industrial symbiosis</td>
<td>- Establish financial and legislative support to promote synergetic industrial behavior (Selmi et al., 2011).</td>
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<td>- Favorable operational subsidies provided by governments (Ohnishi et al., 2012).</td>
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<td></td>
<td>- Policy interventions crucial for industries to engage in Industrial symbiosis (Huang et al., 2019). overnment supported industrial self-organized initiatives favorable (Chertow, 2007).</td>
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<tr>
<td>Governance strategies</td>
<td>- Appropriate policy instruments and subsidies provided by governments (Shi et al., 2010).</td>
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<td></td>
<td>- Adjust incentive structures recognizing positive environmental results obtained by industry (Shi et al., 2010).</td>
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<td></td>
<td>- Guide industries in their waste management, and (Brent et al., 2008).</td>
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<td></td>
<td>- Develop better coordination mechanisms between industries (Brent et al., 2008).</td>
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<tr>
<td>Mechanisms that favor Industrial symbiosis</td>
<td>- Industrial symbiosis to emerge embedded in economic, social, environmental and regulatory reasons. (Chertow, 2007).</td>
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<td>- Cooperation by companies in networks important mechanism for to support Industrial symbiosis (Huang et al., 2019)</td>
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<td>- Institutional capacity an underlying cause for cooperation capabilities (Boons and Spekkink, 2012).</td>
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<td>- Social conditions thus vital for the development of Industrial symbiosis (Simpson, 2012).</td>
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<td><strong>Impact of policy programs</strong></td>
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<td>- Policy programs have vital impact on the deployment of Industrial symbiosis (Jiao and Boons, 2014).</td>
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<td>- Subsidies and legislative conditions are necessary (Van Berkel, 2009).</td>
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<td>- National and local policies have more impact than EU policies to promote synergetic cooperation between industries (Lehtoranta et al., 2011).</td>
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<td>- Incentive based indirect-policy support at the local level more powerful than direct policy targeting Industrial symbiosis (Kim, 2007).</td>
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<tr>
<td><strong>Lessons learned</strong></td>
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<td>- Lessons learned on policy programs etc. supporting Industrial symbiosis (Jiao and Boons, 2014).</td>
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<td>- Strict top-down regulation only is to be avoided (Lehtorante et al., 2011; Kim, 2007)</td>
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<td>- Emphasis on incentives-policy at the local level vital (Kim, 2007).</td>
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<td>- The goal of Industrial symbiosis to be adopted into local and regional policies (Adamides and Mouzakitis, 2009).</td>
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### Table 2: Highlight results from assessment of intragovernmental policy frameworks related to development and operation of industrial symbiosis networks

<table>
<thead>
<tr>
<th>Policy Frameworks</th>
<th>Emphasis / findings of Policy Frameworks</th>
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<td><strong>EU policy</strong></td>
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| Resource efficient (RE) Europe / Roadmap to RE Europe | - EU member states are encouraged to help industries to cooperate to increase their use of waste energy and materials.  
- Extensive savings and earnings are predicted by applying Industrial symbiosis.                                                                                                                                                                           |
| A stronger European industry.....       | - Predicting that European industries will rely on highly efficient manufacturing processes in the future.  
- By applying Industrial symbiosis business models, such efficiencies will be facilitated.                                                                                                                                                                     |
| Circular Economy Action Plan            | - Encourage waste exchanges within industry by clarifying rules regarding by-products within the EU.  
- Create an arena for implementation of Industrial symbiosis throughout Europe.                                                                                                                                                                           |
| Horizon 2020                            | - Support research projects in Industrial symbiosis in the 2016-2017 priority area of 'Industry 2020 in the Circular Economy' focus.                                                                                                                                     |
| **UN policy**                           |                                                                                                                                                                                                                                                                     |
| SCP goal & UNEP                         | - By redirecting investments, apply more efficient technology and better international and national cooperation  
Industrial symbiosis are promoted, and the SCP goals facilitated.  
- Supports the development of Eco-Industrial Parks globally, as regarded superior industrial systems.                                                                                                           |
| Setting up instruments                  | Industrial symbiosis is supported by the UN by the following initiatives:  
- Strengthen and communicating the knowledge base for SCP and resource efficiency.  
- Capacity building within governments promoted.  
- Consolidating and extending business and industry partnerships.  
- Influence consumers in their purchase choice.                                                                                                                                                                                                 |
| Int. Resource Panel                     | - International Resource Panel established to promote resource efficiency and life cycle thinking, through research activities and publications, etc.                                                                                                               |
| **OECD**                                |                                                                                                                                                                                                                                                                     |
| Materials, Resources, Productivity and Environment | - Through stronger cooperation between industries and resource efficiency, enhanced materials management, and the use of sustainable natural resources, circular economy and Industrial symbiosis, can evolve.  
- The three R's are promoted to reach this; the Reduce, Reuse and Recycle initiatives.                                                                                                                                                                       |
| Resource Productivity in the G8 and the OECD | Industrial symbiosis is supported by the OECD by the following initiatives:  
- Greater coherence between different policies.  
- Stronger partnerships between research and civil society and the private sector.  
- Better understanding of the total through-put of materials in our global economy.  
- Increase resource efficiency through shared policies.  
- Allow different solutions in different contexts and governmental levels.                                                                                                                                                                             |

### 4. MEC case analysis

This case describes the initial development and incomplete implementation of the Maabjerg Industrial Symbiosis. The first phase includes planning and construction of the Maabjerg BioEnergy biogas plant as a central unit in a comprehensive industrial symbiosis near the city of Holstebro in rural Jutland, Denmark. The second phase describes how and why the subsequent plans to develop the
Maabjerg BioEnergy biogas-based symbiosis, into a more advanced Industrial symbiosis, through the Maabjerg Energy Center, has been unsuccessful to this date.

4.1 MEC case - phase one

The project takes off in the beginning of 2002, where the initial plans revolves around the building of a biogas plant in Maabjerg, to treat manure from local piggeries, mink and dairy farms. The main purpose is to help farmers live up to new regulation related to protection of local aquatic environments following implementation of Danish law ratifying the EU water framework directive from the late 90’s. In 2004, the process severely picks up speed when a feasibility- and development project is granted 28 million DKK (3.7 million Euro) in financial support from the EU as part of the ECOSTILER project (Energy Supply, 2012). An illustration of the developed project is provided in Figure 1 below, which also show the symbiosis as it looks in operation in 2019. In this constellation of the bio-refinery and industrial symbiosis, the MEC has the following three symbiotic exchange flows with the surrounding society:

1) Exchanges with local agriculture: The facility receives manure from approximately 200 local farmers for the biogas plant and straw from local farmers for the CHP plant. The farmers receive N-rich reject water from dewatering of the biogas plant’s digestate as well as electricity and district heating from the facility.

2) Exchanges with local dairies: The facility receives whey from local dairies for the biogas plant and supplies the dairies with electricity and with biogas for process heat.

3) Exchanges with regional energy and waste sectors: Sewage sludge and slaughterhouse waste for the biogas plant and municipal solid waste and wood for the CHP plant are exchanged with biogas, electricity and district heating.

Fig. 1. Maabjerg BioEnergy biogas plant as conceived in 2002 and as operated in 2019. CHP: Combined Heat and Power station Maabjerg-værket. Numbers refer to policy framework highlights in table 3.

The development period from 2004 until construction starts in 2010 is dominated by; i) time and
resource consuming administrative processes at the municipal level, ii) changing political support
predominately influenced by general elections in Denmark in 2005 and 2007, and iii) financial
uncertainty related to changing framework conditions and the financial crisis in 2008. The project is
very close to being abandoned during this period, but local support, a dedicated consortium and agile
politicians at municipal and national level, carries it through. The whole process, from initial idea to
operation, took 10 years, whereof eight of them where planning, projecting and problems and the last
two were construction and initiation.

4.2 MEC case - phase two

During 2009, even before the minister initiated the construction of the biogas plant at Maabjerg, two
important events occurred that would later help shape the near future for the facility: In EU, the first
renewable energy directive (2009/28/EC) is adopted, establishing an overall policy for the production
and promotion of energy from renewable sources in the EU. The new directive requires the EU to
fulfil at least 20 % of its total energy needs with renewables by 2020 and requires that all EU countries
ensure that at least 10 % of their transport fuels come from renewable sources expected to contribute
substantially to reaching this target (European Parliament, 2009).

Also, in 2009 DONG Energy, one of the MEC consortium partners, start production of second
generation bio-ethanol from straw at pilot scale. The project has been in a development process
running parallel with the development of the biogas facility in Maabjerg. Financial support for R&D
and early operation from EU and DK totaling 40 million Euro has been essential for the realization
of the project (Larsen, 2010).

The combinations of these two events spark an interest in the MEC consortium to expand the
symbiosis to encompass production of second-generation bioethanol. The involvement of commercial
partners in the consortium increase substantially and in 2011, the project is granted 19 million DKK
(2.5 million Euro) from DK R&D funds to further develop the project. The resulting symbiosis outline
plan is provided in Figure 2 below. The integration of a bioethanol facility leads to increased straw
requirements, high internal mass and energy integration and a severe increase in the output of energy
products.

A business plan milestone report from the project determines a set of positive societal contributions
from the investigated system, along with some regulatory challenges and framework conditions that
needs to be resolved to realize the project (MEC, 2012). The business plan is positive for a 20-year
investment decision of a 3.6 billion DKK (480 million Euro) project - total incl. the cost of the already
established biogas plant - if the required framework condition changes are met. The new project is
expected to profoundly increase the economic and environmental benefits of the already established
biogas plant due to the symbiotic nature of the proposed system.

During the following eight years the project was further developed, then finally abandoned and then
again recently revived. Today, it has still not been realized. Initially, the project required four major
framework conditional incentives to make a positive investment decision, being i) Danish tax
exemptions, ii) classification dispensations related to Danish law, iii) politically promoted market
conditions and iv) state guaranteed loans for co-financing the construction. During the development
period, the tax exemptions are partially cleared and a market for second-generation biofuels is
promoted by new policies in EU, fixing minimum blend ratios of second-generation biofuels into
diesel and gasoline (López. 2019).
However, the development of these conditions is long and bendy and along the way the consortium is broken up. The state guaranteed loans for co-financing the construction of the plant is never granted and despite financial support for establishment and operation from EU NER funds of almost 40 million Euro and the Danish government of almost 19 million Euro - a positive investment decision was never realized (MEC, 2018 & Danish Government, 2017).

4.3 MEC case situated in the Industrial Symbiosis policy framework landscape of indirect measures

The MEC case is developed in a policy framework landscape dominated by indirect regulation not specifically aimed towards the area of Industrial Symbiosis. This is supported by a summary of highlight policy framework impacts provided in Table 3. The first phase of the bio-refinery was completed despite several significant barriers related to three main areas:

1. Low value of biogas product
2. High cost of project development and construction
3. Tax on incineration of fiber-residues

The first phase of the MEC system was established primarily to support local agriculture in complying with the new EU water directive framework. The political support to accomplish this task was substantial and the barriers were overcome via supportive political frameworks in the following areas:

1. New energy regulation increasing biogas value via feed-in tariffs for biogas-based electricity
2. New tax regulation related to the categorization of by-products and the potential incineration of these without waste incineration taxes

Fig. 2. Maabjerg Energy Center (MEC) 2013 design. This design is still under development and consideration for realization. Numbers refer to policy framework highlights in table 3.
3. Strong financial support for project development and implementation from EU and Danish funds related to development of renewable energy systems.

It is relevant to notice that none of the barriers – or the political solutions, related directly to the initial local problem with complying to the EU water framework directive.

The second phase of the MEC system was developed with the ambition to create a new-to-the-world integrated industrial symbiosis aiming towards many adverse goals including improved utilization of a local biomass resource (straw), increased value from existing sub-systems (biogas plant and CHP unit), production of advanced biofuels with lower carbon intensity, creating local jobs and economic activity etc. The barriers encountered in this part of the project related to the following main aspects:

1. Establishing a domestic/regional market for second generation bioethanol
2. Support for development and implementation of a new-to-the-world bio-refinery concept
3. Indirect regulation related to IS sub-systems blocking the symbiotic benefits of the entity

The process of resolving these issues were very long but relatively fruitful. In the end, a positive market was established in Denmark and the EU. But the timespan of the secured market was very short and shorter than the return on investment expected in the MEC case. The project also obtained substantial financial support for development and operation. Finally, many of the issues with indirect regulation were also resolved. However, the huge investment required to construct and initiate the core process of the advanced MEC system was never provided. Insecurity on the long-term feasibility of second-generation bioethanol combined with wavering political acknowledgement in Denmark of EU’s proclaimed necessity of biofuels blocked for funding from the sources commonly used in Denmark for large scale critical infrastructure.

Establishing an Industrial Symbiosis by constructing large-scale core-processes to develop a system from detached components is a complex task and success may depend strongly on e.g. the support and robustness of the political landscape and project consortium, long guarantees and increased flexibility in adapting indirect regulation to fit a cross-sectorial, symbiotic purpose.

It is again relevant to notice that none of the barriers – or the political solutions attempted, in the failed attempt of establishing the second phase of the MEC system related directly to the central ambition to create a new-to-the-world integrated industrial symbiosis.

Table 3: Policy frameworks highlights in the Industrial Symbiosis (IS) Maabjerg Energy Center (MEC) case

<table>
<thead>
<tr>
<th>Policy framework</th>
<th>Incentive</th>
<th>Case impact</th>
<th>IS system*</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU water framework directive (2000/60/EC)</td>
<td>New initiatives needed to live up to requirements on protection of aquatic environments</td>
<td>The new framework is the direct motivation for the farmers and municipal stakeholders initiating the development process</td>
<td>Figure 1, sub-system 1</td>
<td>(European Parliament 2000)</td>
</tr>
<tr>
<td>The CONCERTO initiative of the European Commission</td>
<td>Very broad opportunities for funding of energy- and climate related projects involving multiple renewable energy resources.</td>
<td>Provides all funding required for initiation of the development and construction process</td>
<td>Figure 1, sub-system 2</td>
<td>(EU SCIS 2020)</td>
</tr>
<tr>
<td>New political energy deal in Denmark</td>
<td>New, higher feed-in tariff on electricity from biogas CHP</td>
<td>Long-term financial security for electricity product from biogas CHP. Higher, fixed price and longer subsidy period.</td>
<td>Figure 1, sub-system 2</td>
<td>(Danish Government 2008)</td>
</tr>
<tr>
<td>New tax regulation in</td>
<td>Tax-relief on incineration of fiber-</td>
<td>Fibers can be incinerated in waste-</td>
<td>Figure 1,</td>
<td>(Danish Government 2008)</td>
</tr>
</tbody>
</table>
5. Discussion

Obstacles and drivers for deploying Industrial symbiosis based on the previous literature review and the Danish case study MEC are presented in the following section. In the subsequent section, we will propose guidelines to support the formulation of Industrial symbiosis policies in the future. The underlined sentences below, are topics that will be discussed further in the ‘way forward’ section that follows.

5.1 Suggestions based on literature review & European policy frameworks

Literature review: From the findings in Section 3 (see summaries in Table 1 & 2) it is identified that governmental reports dealing with Industrial symbiosis often focus on how policies with a top-down approach and long timeframe, can support such initiatives. Minor emphasis is however on bottom-up policy instruments to motivate stakeholders at the local/company level. This is also concluded by Kim (2007) and Jiao and Boons (2014) in their policy analysis where they find a need for more local and indirect interventions by local governments to create a favorable environment for Industrial symbiosis to develop. We therefore suggest focusing more on the local/company level, and seek to design policy instruments that creates synergy between both levels, as stressed by e.g. Kim (2007), while still acknowledging that properly designed top-down policies including regulation and
taxes/tariffs may also promote Industrial symbiosis.

In Section 3, it was found, that both single and several policy programs supporting Industrial symbiosis have been investigated - within individual countries and across countries - to identify appropriate support. The impact of policy programs has had great influence on the development of Industrial symbiosis. From these studies it is however suggested to provide a clear governmental policy to support Industrial symbiosis (Van Berkel, 2009; Jiao and Boons, 2014; Costa et. al., 2010; Huang et. al., 2019). This is found important especially in the initial stage of the development process. At the same time, flexibility at the local/company level must be provided to adapt to different solutions (Lehtoranta et. al., 2011; Kim, 2007).

The literature review in general identifies that policy interventions are highly important as mechanisms to support Industrial symbiosis, especially in the promotion of self-organization between the stakeholders (Chertow, 2007). But they also stress a lack of appropriate policy interventions, by for example operational subsidies, and general guidance and support to identify waste streams within and between companies etc. (Brent et. al., 2008; Ohnishi et. al., 2012). Lack of such interventions is regarded as obstacles for further development.

The importance of social elements in the development of Industrial symbiosis is also stressed as important and can e.g. be emphasis on networks of companies and self-organizational initiatives adopted by companies. Social conditions are pivotal for Industrial symbiosis to emerge, and must be supported stronger by capacity building within companies (Boons and Spikkink, 2012; Simpson, 2012). Findings from the literature review of case studies in Section 3, lessons learned, suggests supplementing a top-down regulatory approach with a more incentive-based policy (carrot not stick) in the future. Such policies should be applied at the regional and local/company level, if the goal of a more symbiotic society must be reached. Thus, incentive policy at all levels should preferably be provided (Kim, 2007; Adamides and Mouzakitis, 2009). Policy framework: The EU have supported the development of Industrial symbiosis by various initiatives focusing on e.g. resource efficiency, re-cycling of materials and waste, closed-loop activities, circular economy, etc., as well as by funding opportunities within the Horizon 2020 and the structural funds. This support to deployment of Industrial symbiosis from the EU (e.g. research funding, Circular Economy Action Plan, etc.) - hence strong emphasis on materials and energy exchanges - is regarded as valuable incentives, as opposed to direct top-down regulations posed on companies by national states, also stressed by Lehtoranta et. al. (2011) and Kim (2007).

The UN holds many of the same visions for Industrial symbiosis as the OECD and have for decades worked to support the implementation of Eco-Industrial Parks, also in developing countries. They stress the need for life-cycle thinking and resource efficiency and seek, through the work at IRP, to de-couple materials and energy consumption from economic growth. This is for example executed through their promotion of green procurement strategies, which provide a more sustainable marked pull of goods and products. This tool needs to be adopted stronger by national states.

The OECD recommends better framework conditions for Industrial symbiosis, by e.g. suggest stronger co-operation between companies, stronger and shared policies, better understanding of materials and energy flows within companies, as well as more flexible solution applied at the local level when deploying Industrial symbiosis.

5.2 Suggestions based on case study MEC

Obstacles in the development of the first phase of the symbiosis included initial local opposition, slow and resource intensive administrative processes at the municipal level, and uncertainty about
framework conditions on the national and supranational level. While the local opposition could be quickly resolved, by an early effort involving direct communication and constructive meetings, the administrative and legislative processes were out of the consortium’s control.

Industrial symbiosis systems that span across multiple sectors are commonly described in the academic literature, and the same cross-sectoral features can be found in the MEC case that integrates energy production (biogas, heat and power), agriculture (slurry and agricultural waste), food production (dairies and slaughterhouses) and transport sector (biofuels). As the MEC system originally was designed as an integrated concept, the project consortium had to deal with several legal frameworks at the same time: the first phases primarily with agricultural, energy and waste legislation, associated with construction of the biogas plant and in the later phases of the project, primarily with energy legislation related to market conditions for second generation biofuels, support schemes for investments in energy plants as well as various tax and classification issues related to the incineration of fiber residues and the appropriate categorization of the system.

The sector integration issue may be difficult to handle by local authorities due to unprecedented cases and inflexible formulation of laws and regulation. Industrial Symbiosis systems are often highly situated cases that will be unlike any other handled by the local authorities. Inflexibility and sector-division of policy and regulation can be problematic since the responsible political actors may be hard to identify and unaware of their responsibility. This was experienced in the early stage of the biogas plant at local level, national level and even at EU level. The delegation was first sent to talk to officials working with traffic since then to the agricultural section and finally to commerce and competition.

Also, utilization of by-products and waste resources may often cross the boundaries between public and private entities and an effort should be made to ensure that the available options and related regulation is fit for this task. There may be a lack of sufficiently precise and flexible language in the legal system to develop suitable over-arching regulation that can promote new, cross-sectoral systems in optimal ways. As it was the case for the MEC system phase 2, there may be e.g. utility production and use issues, tax issues and financing options that are only developed for private or public entities and not for hybrid constructions. In the MEC case it was argued that such a system was critical to society to enact a transition of the transport sector and therefore, it should be a public-private entity with the same favorable financing options as heat and power stations. However, legislation was not flexible to adopt new types of systems in pre-established frameworks and it is not easy to pre-conceive the nature of designs that do not yet exist. Therefore, development of policy and legislation should include considerations of how this regulation would influence new-to-the-world industrial symbiosis concepts.

The trans-sectoral nature of the symbiosis concepts is also problematic in relation to contradictory regulations in the different laws as well as in relation to local municipalities met with unprecedented legal issues and comprehensive law complexes. The local authorities may become overly cautious and reluctant to rule and make decisions in cases where the consequences are unclear. We therefore suggest a potential solution to accommodate these issues being the establishment of centralized cooperative authorities on regional and national level to run such projects. Such central organs would facilitate build hands-on experience much faster than is the case in decentralized systems and would be faster to establish a knowledge base and catalogue on previous cases, procedures and obstacles. It would be possible to gather more specialized competencies and it would make it easier to collect input for policy development.

Due to the complexity of symbiosis projects and the potential large scale and reach of the systems, funding schemes have to be flexible enough to allow for very long term development, increased risk
of unforeseen delays and substantial uncertainties. We therefore suggest to earmark such flexible long-term funding options for symbiosis projects within the EU. Successful application for such funds should provide project development with a higher level of security and therefore have very long – and flexible, deadlines for realization of the funding and support. Presently, the relevant public funding support is often relatively short-sighted and the lack of flexibility and security may increase uncertainty and volatility in the project which is very problematic when dealing with development of large, complex systems.

Finally, a well-founded positive support at the local, regional and national authorities was found in the MEC case to secure continuity in project development, as the planning and development process may span across the temporal scope of the average politician’s position. If decisions may change with the interpretation of the policy framework, then substantial – and unexpected, setbacks may occur in parts of the development that was otherwise perceived as being settled.

The main policy frameworks governing the outcome of the MEC case are summarized in Table 3. The findings in the case support the conclusions of e.g. Costa et. al. (2010) regarding the need for clear governmental policies at the highest level combined with improved options for flexibility on regulation at the local level. It is also expected that the recommendations by Laybourn and Lombardi (2012) on new policy frameworks targeting industrial symbiosis, with statutes bridging e.g. green growth, innovation, eco-efficiency etc., would have supported the development and implementation process of the MEC case. On the other hand, the case does not support the apparent need to establish centralized energy- and material exchanges as the stakeholders in the MEC consortium already had a broad network across academia and industry supplying ideas, information and contacts to support development of the symbiosis.

5.3 Way forward

From the literature study a lack of appropriate policy interventions (Brent et. al., 2008; Ohnishi et. al., 2012) have been identified as an obstacle in a further deployment of Industrial symbiosis. There is also, as indicated above, a need to develop incentives policy at all levels (Kim, 2007; Adamides and Mouzakitis, 2009), and to provide valuable incentives as opposed to direct top-down regulations only, as argued by Lehtoranta et. al. (2011) and Kim (2007), as well as the EU. We thus suggest a combination of a firm regulation providing policy interventions together with more incentive-based initiatives especially at the local level. The analysis in this paper therefore suggests that both direct and indirect policies influence the development of industrial symbiosis systems.

The case study, on the other hand, illustrates that development of industrial symbiosis systems is influenced by policies in complex ways and often influenced by policy frameworks that have been developed with other aims and targets than industrial symbiosis as such - the success and failure of the MEC system is for example depending a broad set of rules and regulations spanning from EU level biofuel market to national Danish regulation of business models in the heating and electricity sector. Direct and indirect policies should therefore not be two competing forms of regulation but rather as mutually supporting regulation.

As a way forward for future regulation we suggest that while formulating direct policies to support industrial symbiosis policy makers and involved stakeholders should pay attention to how existing regulation may or may not hinder or promote industrial symbiosis. In that respect, alignment of direct industrial symbiosis policies with the broader framework of indirect policies may an important challenge to solve. This is emphasized in the following:

**Indirect policies:** Based on knowledge from the literature review, we suggest to favoring higher and
penalizing lower waste hierarchy waste management. This could e.g. be by requiring high taxes on landfill and incineration of waste, bans on landfills organic waste, and 'pay-as-you-throw' schemes, as this will incentivize changes.

**Direct policies:** We also suggest providing incentives to companies by e.g. government programs, through for example, an expert travelling teams, who assists companies at the local level, as well as other local level stakeholders (municipalities), in addressing Industrial symbiosis. Also, co-operation platforms can be facilitated by government (see later) in which a fruitful environment for inter-company collaboration can be established.

Such governmental interventions can be formulated within the frame of an overall national Industrial symbiosis strategy and could provide a clearer governmental policy, as requested by Van Berkel (2009); Jiao and Boons (2014); Costa et. al., (2010) and Huang et. al., (2019). Such governmental policy should also provide funding for companies to initiate various symbiotic activities. These issues are also noted by Johnsen et. al. (2015), who stresses that an overall governmental policy including funding opportunities, can be a strong driver for a further development of Industrial symbiosis.

**Stronger and shared policies** initiated by governments, addressing both stronger waste management practices and incentive policy at the low levels (company), are thus, according to the OECD, important to apply. In the following, we will provide recommendations of which further initiatives governments could initiate in their incentives policy at the local level.

**Cooperation between companies:** We find it necessary for companies to have access to platforms where they can meet and start co-operating, as a need for stronger co-operation between companies currently are identified as obstacles, by e.g. the OECD. Within such platform’s sellers and buyers of by-products etc., can be introduced to each other, and provide a communication tool that currently lack and act as barrier for a further development. When such platforms are in place, they would facilitate more self-organizing initiatives between companies (Chertow, 2007) and hence constitute a driver for further development. Municipalities, or other types of important local stakeholders, should take part in these platforms, and assists in the work of maintaining and developing them further. This is also stressed by Johnsen et. al., (2015), who point to the importance of local processes, as drivers in greening the economy.

More focus at the local/company level (Kim, 2007) is therefore a necessity to promote synergy-related networks. The co-operation platforms, mentioned above, can therefore facilitate such initiatives, in which, according to the OECD, context specific and flexible solutions are applied. Thus, here can more generic solutions be avoided and more emphasis is given to adaptation and flexibility at the local level (Lehtoranta et. al., 2011; Kim, 2007).

**Knowledge gab:** The current obstacles for Industrial symbiosis, related to the need better understanding of materials and energy flows within companies, as stressed by OECD, a genuine problem related to stakeholder’s knowledge gabs. It is therefore important to establish and facilitate environments to learn about symbiosis techniques, valorization of e.g. companies waste streams to be aware of Industrial symbiosis opportunities within company and between other companies. Such learning environments could fill out the current gab of know-how regarding appropriate technology, appropriate types of and re-use opportunities. ‘Speed-dating’ opportunities between companies could for example be provided, where they meet and join forces. This could be an important future driver.

Noted by Interreg Europe (2017) is the importance of companies to learn about funding opportunities, various support initiatives and potential investors to back up the materialization of the identified symbiotic opportunities. This could for example be provided by the platform above and therefore be an important driver for change through capacity building within companies and hence awareness rising among the stakeholders involved (Boons and Spikkink, 2012; Simpson, 2012).
Market demand: Another obstacle is the lack of market demand for certain products and goods that are produced with focus on materials and energy usage. Local businesses, authorities and governments, etc. must strengthen their support to green procurement or use of certain goods or services produced within ‘industrial symbiosis, as sustainable products (Intereg Europe, 2017). Thus, promotion of green procurement strategies could, according to the UN, be a good driver and opportunity for companies to promote a green profile and gain competitive advantages and increase access to new markets.

Centralized cooperative authorities: Experience from the MEC case exemplifies how municipal level legal processes can be prolonged and influenced by high uncertainty when related to unique complex industrial concepts. It is therefore suggested to establish centralized cooperative authorities on regional and national level to run such projects. These units could establish competences, knowledge and networks to deal with unprecedented, complex cases, faster and much more efficiently, and would better be able to predict and coordinate the process and thereby support the development of symbiosis and bio-refinery systems. Development, as well as implementation of new framework packages on e.g. circular bio-economy, bio-resource efficiency and Industrial symbiosis systems, would also become faster and better. Concentrating these competencies would also enhance a potential for more international exchange of knowledge and experience and provide more qualified input for supra-national policy development.

Flexible funding schemes: Ideally, funding granted for development of complex industrial systems should remain open and available despite substantial delays and changes in the project. The need for more flexible funding schemes was also exemplified in the MEC case, where uncertainty about the possibilities to reach development targets to comply with fund-use deadlines induced substantial uncertainty and nerve in the consortium and development process. Prolonging or removing fund-use deadlines would to a larger extent contribute to process stability instead of increasing project volatility. In the present case, it was seen at least twice how funds were granted with a relative short deadline adding uncertainty on uncertainty around the project’s success when delays or unforseen changes in the project development occurred.

Local political and public support: From the MEC case it is further revealed, that broad as well as targeted communication about project driven increased value and job creation potential, can benefit such projects substantially. Symbiosis project ideas should gain positive position in the local, regional and national environment. Learnings from the MEC case points out how locally relevant impacts like e.g. job creation may be a forceful driver on the local political level but less so on the national and supra-national level. Identifying and promoting political gains on all levels of the governance structure, may therefore increase the chance of project success.

6. Conclusion

Departing from the policy analysis we suggest supporting the deployment of Industrial symbiosis through the following initiatives:

The review of industrial symbiosis literature identified potential policy drivers and suggest that governments could support industrial symbiosis development by providing economic and policy instrument. Such policies could for example favor higher- and penalizing lower waste hierarchy waste management practices within companies. These initiatives could include high taxes on landfill and incineration of waste, ban landfilling of organic waste, and ‘pay-as-you-through’ schemes, as this indirectly will create changes.

According to the research findings in this paper an important driver for industrial symbiosis
development is the implementation of incentives-policies and support to companies at the local level, hence providing more fertile conditions through bottom-up strategies in the local communities. Here, indirect policies like land use regulation and planning, and waste policies, can work as a vital driving force (Kim, 2007; Lehtoranta et. al., 2011; Adamides and Mouzakitis, 2009).

Besides this, the analysis indicates that access to platforms where companies can collaborate in some cases can function as a driving force. Within such platform’s sellers and buyers of by-products etc., can be introduced to each other, and provide a communication tool to overcome the obstacle related to insufficient knowledge about potential symbiotic partners.

The literature indicates that many stakeholder’s have knowledge gaps as far as Industrial symbiosis. The analysis suggests that establishing and facilitating learning environments related to symbiosis techniques can act as a driver in the development process. Such learning environments, as e.g. workshops with company speed-dating, could fill out the current gap of know-how regarding appropriate technology, appropriate types of and re-use opportunities.

Knowledge about funding opportunities, various support initiatives and potential investors to back up the materialization of the identified symbiotic opportunities was identified in the literature study as potential drivers for symbiotic development. Also, according to the analysis on policy programs, local businesses, authorities and governments, etc. could contribute to symbiotic industrial developments by adopting green procurement or use of certain goods or services produced by ‘industrial symbiosis. This can strengthen the market demand and pull effects.

The MEC case analysis illustrates how policies and regulation, not focusing specifically on the implementation of Industrial symbiosis, is often the most important drivers for the plants’ actual realization, exemplified by e.g. the biogas feed-in tariff scheme. This was seen also in the literature review, where several studies have recommended more bottom-up incentives, and concluded that indirect policies may often have a higher impact compared to the direct policies targeting Industrial symbiosis.

The work with the MEC case exemplifies drivers and obstacles related to the situated context. In the specific case, these include the potential value of for example; i) more flexible funding schemes with longer or no fund-use deadlines, ii) establish centralized cooperative authorities on regional and national level, iii) local political and public support, with special emphasis on identifying and promoting values on multiple government levels. As the nature of a case is highly context specific, a more comprehensive effort would be required to unfold the case-based findings into general recommendations. In such endeavors, the current findings should serve as an indication of relevance and as inspiration for further studies.

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