Sustainable expansion of biogas from secondary inputs in the European Union

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Abstract

This project examines the possibilities for the EU to create favourable conditions for a biogas expansion with secondary resources as input material. Biogas is a biofuel that has a number of environmental benefits, the most important one being recycling of soil nutrients, such as phosphorus, at the same time being a safe means to treat waste and thus contributing to creating a circular economy. The case of Germany as the largest biogas producer in the EU is examined. It is determined that the main driver for the development is the large degree of support through feed-in tariff policies and allowing energy crops to be the main input. It is also determined that a transition to secondary resources is necessary. Based on interviews with national experts from Germany and Denmark, the following issues related to the transition are highlighted: low methane yield of manure-based biogas, not including input vendors in remuneration, limited incentives for separation of biowaste, lack of incentives for using rest heat from biogas, lacking differentiation between biomethane and natural gas in the law, missing infrastructure and low RE quota in transport sector and treating digestate in the same way as untreated manure in the policies. Creating favourable conditions for development of sustainable biogas requires following prerequisites from the EU: targets for bio-waste separation; involvement of multiple stakeholders in the international guidance for the FIT scheme and/or further incentivisation of anaerobic digestion through its agricultural policies; harmonising rules for digestate content across countries; common sustainability standard for biogas.

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Chapter one: Introduction

Problem Area

The way the society functions is highly dependent on the supply of energy, which, as of today, is mostly based on fossil fuels, such as coal, oil and natural gas. These materials provide us with electricity, gasoline and heat: inevitable elements that shape the society of the present day. These materials, however, are non-renewable, as they release carbon dioxide and other greenhouse gases when incinerated. The release of greenhouse gasses into the atmosphere has consequences for the climate. The United Nations International Panel on Climate Change (IPCC) states in the most recent special report on climate change that *"Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C. Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate."* (IPCC 2018). In order to mitigate these climate risks, the United Nations Framework Convention on Climate Change (FCCC) developed a set of goals, known as the Paris Agreement, which was signed in 2015 (COP21) by 174 countries of the world and the European Union. The long-term overall aim of the agreement is, based on national determined contributions, to stay below a global temperature rise of maximum 2°C, and preferably 1,5°C degrees, compared to pre-industrial levels (FCCC 2015). To reach this, the IPCC recommends that the world CO_2 emissions be reduced with 25% by 2030 (2°C pathway) or 45% by 2030 (1,5°C pathway), compared to 2010 levels (IPCC 2018). The demand for renewable sources of energy that can reduce carbon emissions is therefore increasingly in demand. Globally, the share of renewables in gross energy consumption constitutes 13,7 % of overall demand as of 2016 (EC 2018a).

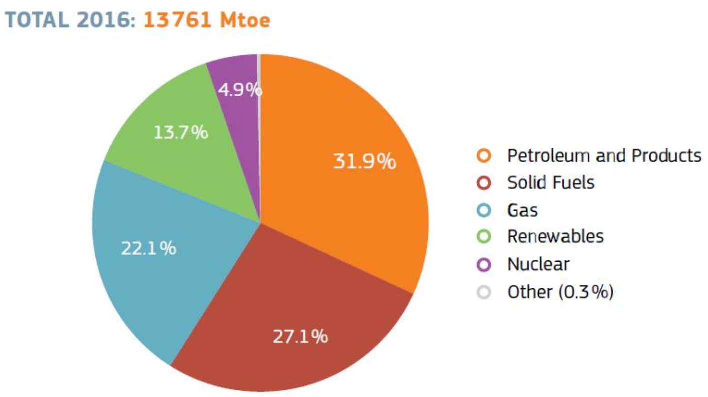


Figure #1: World gross energy consumption by source (EC 2018a:13).

Renewable energy can be produced from several sources (Renewable Energy Sources, RES) that all contribute in meeting the demands of heating and cooling (RES-H&C), electricity (RES-E) and transport fuel (RES-T). The Renewable Energy Directive (RED) defines renewable energy as *"energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas"* (EU 2018).

Biogas is of great potential to meet these demands, and can potentially play an important role in the future renewable energy landscape. A biogas plant is a controlled environment, where natural decomposition process of organic material takes place. The process is anaerobic (oxygen-free), humid, and it generates heat and gas. The input can be any sort of organic material, but one of the main advantages of biogas is that it is possible to constructively use organic residues like agricultural waste, manure, food waste and sewage sludge. There are two products of the process: one is *biogas*, a gas consisting of mostly methane and CO_2. The second product is *digestate*, the dry matter leftover that cannot be further decomposed, which can be used as agricultural organic fertiliser. The gas can be used for electricity generation, upgraded and used as transport fuel or simply injectected into the local gas grid to be used for e.g. cooking as a substitution for natural gas.

The environmental benefits consist therefore by and large of substituting fossil fuels in the production of electricity, heat and transport fuels, which means that no extra carbon is released into the atmosphere as the organic material already in circulation is used as a primary energy source (Energistyrelsen 2016; Gustavsson et al. 1995; Cuellar et al. 2008). Benefits of this also include a decrease in e.g. water, soil and air pollution and a reduction in greenhouse gas emissions (GHG) (Scarlat et al. 2018a). In addition, when biogas is produced from manure or landfill gas, it systematically captures methane, a powerful greenhouse gas, that is otherwise released into the atmosphere when stored; this, in theory, makes the process carbon-negative (EU 2018). The digestate, on the other hand, can serve as a nutrient-rich fertiliser that can substitute mineral fertilisers, primarily through recycling of phosphorus that in the near future can become a scarce resource. The use of digestate as fertilizer can also have an effect on the nitrogen balance in the soil, as nitrogen becomes more accessible for the plant to absorb (Möller & Müller 2012) and therefore prevents potential nitrate leaching and eutrophication. This, however, is disputed in scientific literature (Svoboda et al. 2013). Furthermore, on a larger perspective, Poeschl et al. claim that biogas is *"arguably a more versatile renewable energy source (cf. wind and solar energy), due to its determinate energy value and ease of storage, hence, potential utilisation is significantly independent of factors such as geographical location and season"* (Poeschl et al. 2010). It is clarified that *"Because biogas can be stored, electricity generation can systematically be increased when consumption is high or it can be reduced at times of low demand"* (GBA 2011:13). Because of this, biogas can play an important contributing role in energy-diversification and have a "back-up" function in an energy grid based on fluctuating energy sources such as wind and solar photovoltaics.

Because of these benefits, biogas has in the recent years become an attractive pathway to expand the renewable energy shares (Scarlat et al. 2018a). However, a very important factor to make the biogas production sustainable is input. The anaerobic digestion process can use a wide variety of inputs: manure from livestock, food and industrial waste, wastewater or energy crops grown for the purpose, such as maize. Energy crops, and especially maize, have been widely used as primary inputs for generating biogas; the risk of indirect land-use change (ILUC), that is, adapting land that originally was not cultivated for agricultural use, is associated with production of energy crops to meet energy demands (Lijó et al. 2017). There is also a risk of widespread feedstock forming just for the purpose of energy production, instead of food crops, which relates to the global problem of food shortage (ibid.). This is an important factor to consider when planning sustainable expansion of the biogas market.

When it comes to electricity production from biogas, the European Union is leading with a capacity of 10,4GW (Gigawatt) out of the global 15GW in 2015 (Scarlat et al. 2018a).

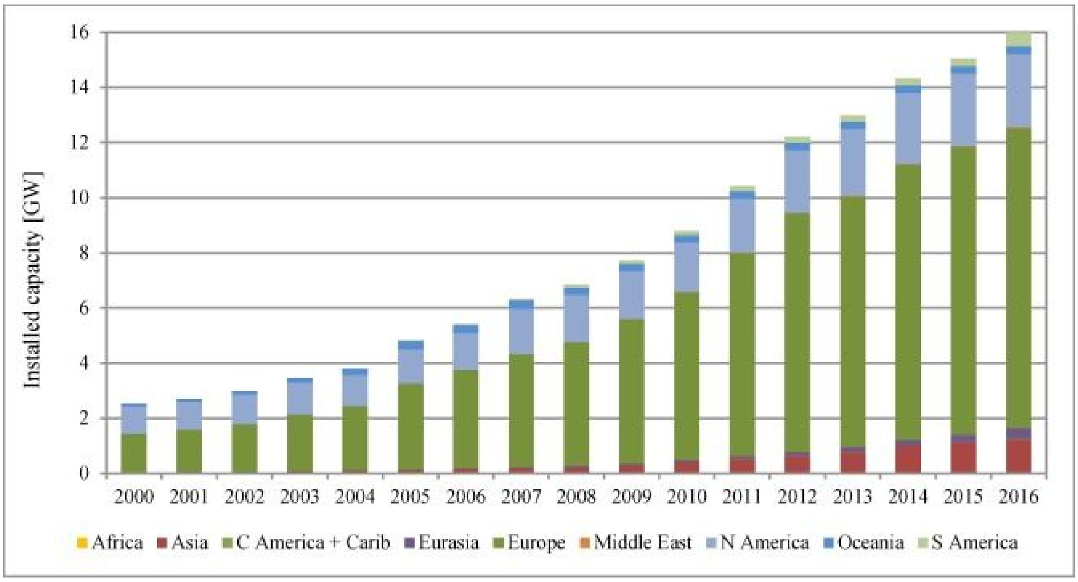
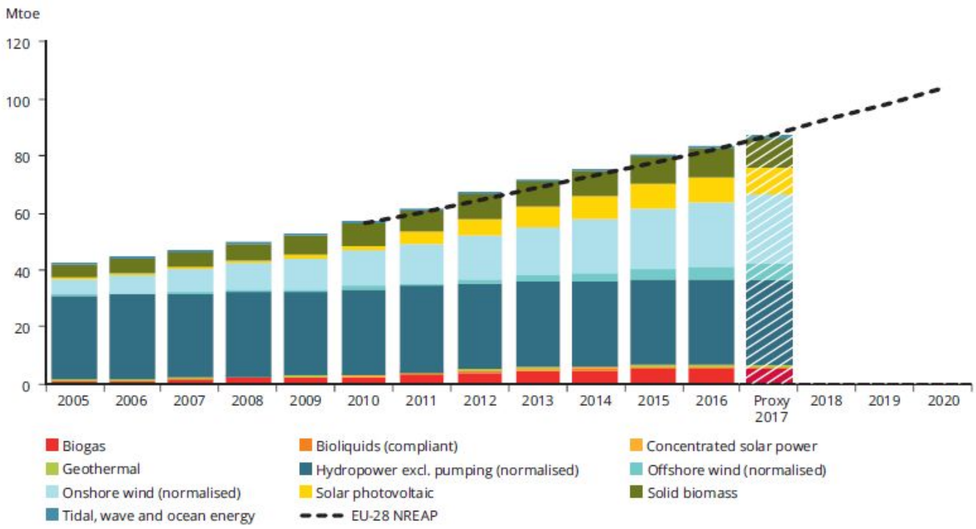


Figure #2: Evolution of global installed electricity biogas plant capacity (Scarlat et al. 2018a).

The share of biogas in the overall electricity produced from RES, however, is only starting to be noticeable on a larger scale (see figure #3). With the beneficial impacts that the production of biogas carries, biogas production has a high potential for development, especially in the waste sector (Pazera et al. 2015): *"The advantages of waste biogas plants are the generation of renewable energy in a closed loop (cascade utilisation of waste and digestate) and the fact that no agricultural area is required for biogas production"* (Pazera et al. 2015).

Figure 2.5 RES-E in the EU



Notes: This figure shows the actual final RES-E consumption for 2005-2016, approximated estimates for 2017 and the expected realisations in the energy efficiency scenario of the NREAPs for 2018-2020. Wind power and hydropower are normalised. The consumption of RES accounts for only biofuels complying with the RED sustainability criteria.

Sources: EEA; Eurostat, 2018d; NREAP reports.

Figure #3: Electricity produced by renewable sources in the EU by source (EEA 2018).

The reason for the relatively low share of biogas is an economical one. For the biogas market to expand, there is a need for investment incentives. As both the European Commission (EC 2016a) and other studies underline (Scarlat et al. 2015; Torrijos 2016; Dzene et al. 2012; Chinese et al. 2014; Pazera et al. 2015), there is a clear correlation between national policies made to promote renewable energy and the development of biogas plants; a prime example of that is Germany. The 2001 German EEG (*Erneuerbare-Energien-Gesetz;* the Renewable Energy Act) introduced the *feed-in tariff*, a policy that ensures a return of investment and profit in 20 years, which, according to Pazera et al. (2015) has been a generous subsidy. A clear increase in amount of biogas plants was observed during the following years. Likewise, the German development of biogas plants stagnated in 2014 as a result of a change in policies (reasons for this are explained in chapter five: Germany, RE & Biogas), making investments in production of biogas less economically attractive (Pazera et al. 2015; Torrijos 2016). Nonetheless, Germany is still accountable for by far the largest part of the electricity produced from biogas in the EU (see figure #4), and also holds the largest amounts of biogas plants followed by Italy and France (Torrijos 2016).

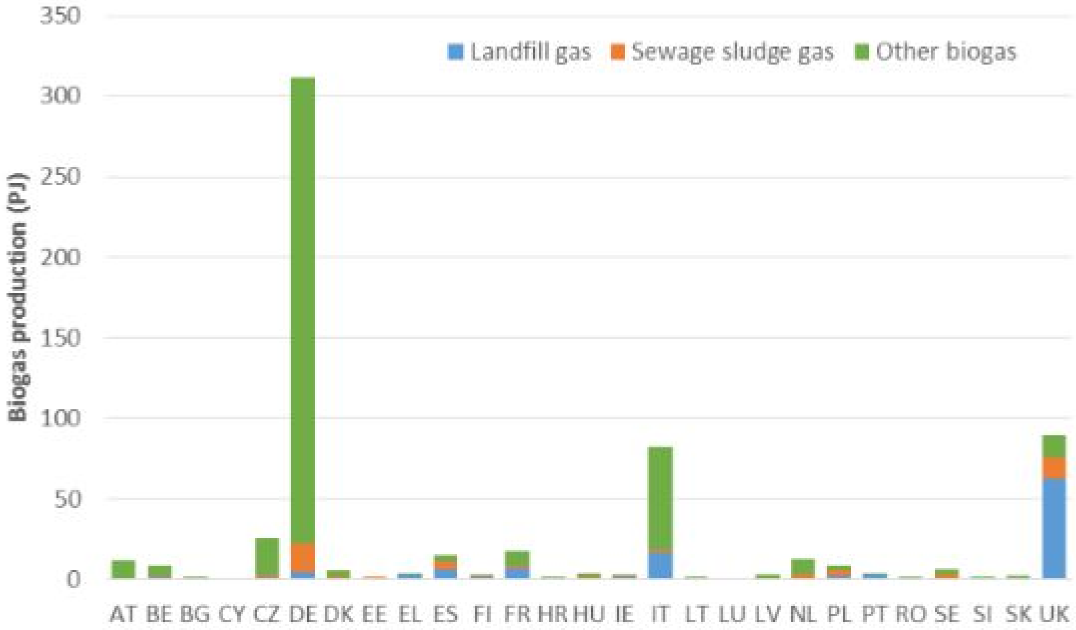


Figure #4. Biogas production per Member State in 2014, differentiated by source (EC 2016a).

The expansion of biogas plants and biogas production is therefore under great influence of policies and support schemes. The Executive Director of the International Energy Agency (IEA), Dr Fatih Birol underlines that: *"Over 70% of global energy investments will be government-driven and as such the message is clear – the world's energy destiny lies with decisions and policies made by governments."* (https://www.iea.org/weo2018/) which is clearly quoted in a "world energy outlook 2018" context on the agency's website.

This calls for a thorough consideration of the effect of future policies on renewable energy. On the basis of the EU-determined target of a share of 20% renewable energy in 2020, the EU recommends a set of policy templates that aim to develop sustainable deployment of biogas production, allow biogas production projects to develop, and market demand to grow (EC 2016a). EU has a clear interest in promoting the success and development of the business, trade and industry of the biogas production and use, but the authority of the EU is very limited. Based on their position, an assessment report from 2016 (*Optimal use of biogas from waste streams - an assessment of the potential of biogas from digestion in the EU beyond 2020*) has been produced to present the status of biogas production, the drivers and barriers for development and policy recommendations on both the EU and national level. These will be examined further in this report.

As the EU Directive on promotion of use of energy from renewable sources expresses, the 2020 target relies on legally binding national targets until 2020 (EC 2017). Each Member State submitted these as National Renewable Energy Action Plans (NREAP) based on the difference in the resources available in each country. The current NREAP's are effective until 2020, and were all produced in 2009, in exception of Czech Republic who revised their targets in 2013 (EC nd.). This also means that a new set of targets is under construction, and that changes will be made within the next few years.

This report seeks to address these policies and examine to what extent they are sustainable, environmentally, economically and socially and how they can potentially be improved. The aim of the project is to create a recommendation for an EU policy that would serve as a frame for the policies in EU Member States that would generate incentives for investments in production of biogas from sustainable inputs. The recommendation would, unlike the *Optimal use of biogas*, not focus on the assessing the potential of biogas, but on concrete policy measures.

Based on the above research problem, the project will aim at answering the following research question:

How can the EU create a frame for Member States policies that would promote sustainable expansion of the biogas industry, while promoting secondary resources as inputs?

In order to provide an adequate answer to the research question, the following sub-questions will be answered:

1. *How does biogas technology work and how can its products be used?*
2. *How can the state-driven support schemes promote investments in biogas and how have these contributed to the development of the biogas industry in Germany?*
3. *What are the main challenges that should be addressed when creating optimal conditions for biogas from secondary inputs to develop?*

The sub-questions will be answered in different chapters in the project. The table below illustrates which chapters reply to the question.

Subquestion	Chapter
1	3
2	4-5
3	7

Figure #5. A table showing where the answers to the respective questions can be found in the project. Own work.

Terminology clarification

This chapter will clarify a number of notions that will be frequently used throughout the project.

Sustainability

The problem definition refers to "sustainable expansion of biogas industry" and sustainability is often referred to in other parts of the project. The term "sustainability" can be traced back to the 18th century and has developed into being a very well-established term in global politics, economy and society (Spindler 2013:9); its most widespread meaning has its origins in the 1987 Brundtland Commission report that describes sustainable development as the development that "*meets the needs of the present without compromising the ability of future generations to meet their own needs*" (UNWCED 1987). The use of the term in this report is rooted in this definition, while also drawing from the 2005 UN World Summit, where sustainable development goals have been described as "*environmental protection, economic development, and social development*" (UN 2005).

European Union (EU)

The project mentions the EU on numerous occasions, including in the problem formulation, where it is the subject that is to *take action* and *create a frame for Member State policies*. The authors are aware that the EU is not a single governing body and has a number of institution, each having different competencies; discussion of these concrete competencies is out of scope of this project. The EU should, instead, be seen as a supranational system for decision-making and in terms of broader environmental governance, its goal is seen as creating policies that encourage (not force) the Member States to take concrete actions.

Member States

The Member States are often named in the project as subjects to the EU's policies. What is referred to as the Member States here are the 28 national states that currently are members of the European Union and the organs responsible for policy-making in each of the state. Detailed political, structural and institutional discussions of each Member State are out of scope for this project.

Secondary resources

One of the main premises of the project is that secondary resources are the desired inputs for biogas production. These are otherwise often referred to as biodegradable waste materials. While this project does use the terms "municipal waste", "industrial waste" etc., these, along with manure and wastewater, should be treated as categories under the umbrella term "secondary resources" describing all potential biogas inputs that are not specifically produced for the purpose of biogas production and traditionally treated as unwanted. The terms "municipal waste" and "industrial waste" refer to waste that is chiefly composed of organic matter (also known as bio-waste), unless specified otherwise.

Scope definition

This project analyses the biogas system in the European Union, using Germany as the case example. The biogas industries in other Member States, despite the project's conclusions being relevant for them, will not be elaborated upon in detail, while the biogas industry outside of the EU is not within the project's scope.

The project includes a description of the anaerobic digestion technology and reflects upon barriers and challenges for its sustainable expansion; the described system is, however, limited to the biogas plant itself and the inputs are discussed largely in quantitative terms; this means that the infrastructure surrounding e.g. the delivery of input, collection of waste etc. is not discussed. The project focuses mostly on manure and municipal waste and also shortly discusses the idea of using wastewater as secondary resource inputs for biogas production.

The authors acknowledge that there is also a number of other possible inputs for biogas production, but these will not be discussed in the project.

The empirical part of the project is made up of interviews with experts, all representing organisations working both with biogas producers and lawmakers; the authors acknowledge that other stakeholders, such as citizens, investors and owners of biogas plants, may have large relevance for the issue in question and recognise that they should be included in any kind of planning. For practical reasons, however, these stakeholders have not been consulted.

The authors are also aware that the question of biogas expansion is largely dependent on the political landscape of the European Union and each Member State; without favourable attitude of the influential part of the political universe, development of the biogas sector is not likely to be realistic. The authors, however, do not wish to involve nor side with any concrete sides of the political spectrum in any realm, be it EU or any Member State. Thus, political discussions will not be included in the project.

Chapter two: Project design

The project will be rooted in the background section, where the biogas technology, the support schemes are described and the case of Germany is presented. Afterwards, the project analysis is described, built on the theoretical background and empirical data from interviews. Lastly, building on the gathered data, using the Multi-Level Climate Governance theory and supplying with additional literature study, the policy recommendation is suggested. This design is visualised with the model below:

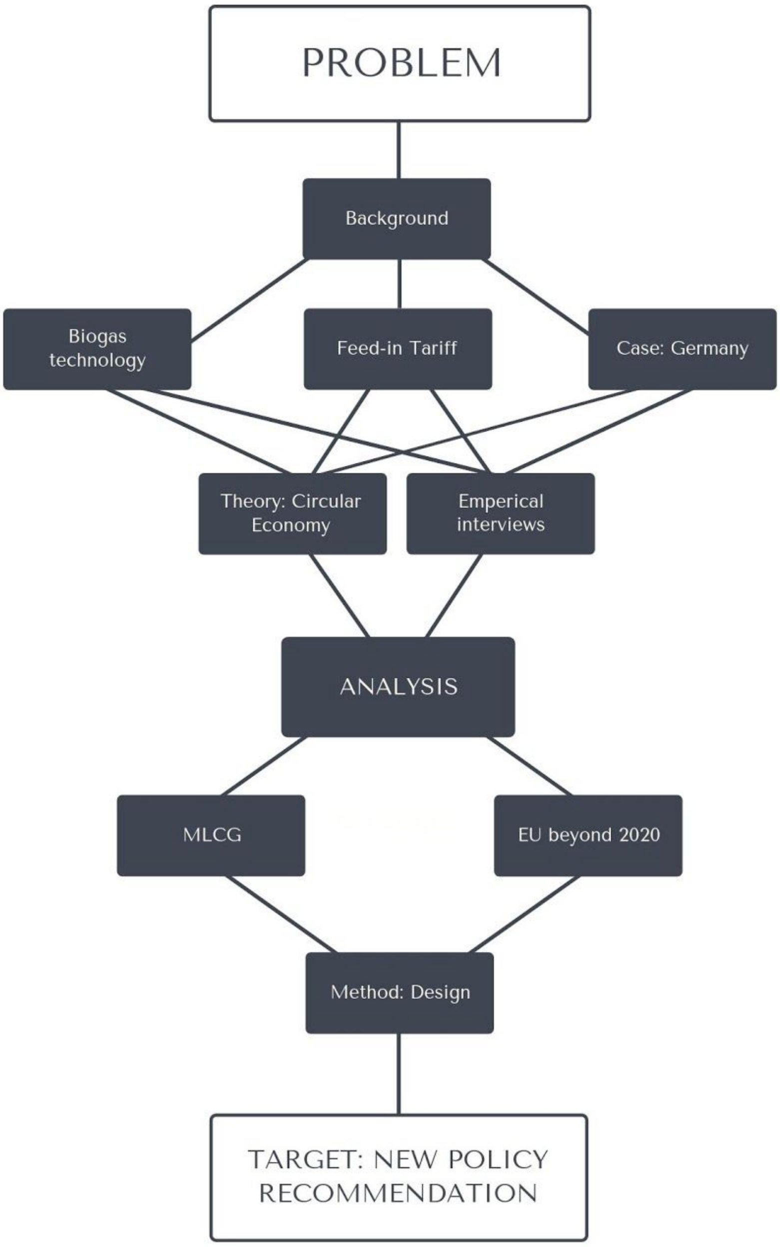


Figure #6: Visualisation of the project design. Own work.

Dimensions

The project draws from all three Hum-Tek dimensions. The use of Design and Construction (D&K) is expressed through the wish to design the solution to the issue using the methods learned during the course, including the Project Cycle Management (see: methodology). Technological Systems and Artifacts (TSA) will be used through the technical description of biogas production system, whereas Subjectivity, Technology and Society (STS) will be expressed via our reflections on how the aspiration for creating a sustainable future and retaining the life standard of the current society can be maintained through technological solutions, biogas being one of them.

Technological Systems and Artifacts (TSA)

In the TSA dimension, considerations are made about how a specific technology is engineered and what role it plays in society. A technology can emerge from a certain demand or as a "problem solver" in a certain context. TSA also concerns the effectivisation and spreading of technology, and the emerging of a technology can be observed through an innovation curve (Rogers 2003), where a technology often passes a point of critic mass before being adopted as mainstream technology. A technological system is characterised by a technology integrated in a network, as biogas can be dependent on suppliers and connection to actors making use out of the outcome, which again upholds the demand. This, as more external technology starts to adapt to the specific system, for example the development of vehicles with motors adapted to upgraded biogas as fuel. The biogas plant itself is consisting of tanks and filling systems that are specialised by function. These considerations are applied within subject of the report.

Subjectivity, Technology and Society (STS)

STS is about the considerations about the assessment on the way technology affects the individual and the society. Through this dimension, a social perspective is included in dealing with the problem of expansion of biogas production, in which several actors are relevant, e.g. the citizens living near a biogas plant, as it is emphasised in the theory of Multi-Level Climate Governance that public recognition is significant in whether a technology is liked or detested. Communication about the way the technology can potentially) affect one's living standards is crucial in such situations. As an example of this, a relevant problem of the biogas sector's relation to the society is addressed, regarding the *Not In My Backyard* (NIMBY) phenomenon throughout the project to realise this dimension in the considerations.

Design and Construction (D&K)

The design aspects affect this report through the assumption that a general solution is working best when sociological and technical considerations are included. By solution meaning that this report emphasises how policy-making has an immense effect, and that by theories the most effectful policies are considerate of more aspects than only technical and economic. Therefore, in this case, general design method is used that rises the questions of holistic problem solving that meets the highest levels of a sustainable design possible, across more aspects than one. We here try to approach a solution through problem identification and the Project Cycle Management.

Methodology

The project employs two methods: interview as the main method for gathering empirical data and Project Cycle Management as a background for creating a policy recommendation using the gathered empirical and secondary information. The methods and their functions are described in detail below.

Interview

The project employs qualitative expert interview as the primary method for gathering information. Qualitative research seeks to gain deeper knowledge of the given phenomenon, rather than quantify it. The research is largely based on the specific case of Germany's RE policies and seeks to formulate universal guidelines for policymakers. We would argue that due to the context-sensitive nature of this problem, it is necessary to gain detailed knowledge of the context. Therefore, to formulate a universally applicable policy recommendation that the solution-makers could ultimately use as a framework, it is necessary to base the generalisation on the logic we can draw from this particular case, rather than generalise on the basis of many occurrences that could then be quantified with quantitative research. In this way, the project uses the inductive approach, where it is the premise that together with some evidence give validity to the conclusion (Goddard & Melville 2004).

The primary reason for choosing interviews as the primary method is the complexity of the problem field; interviewing experts with different backgrounds serves as a means to gain a holistic perspective on the issue and allows us to gain a knowledge that otherwise would be difficult to gain through literature study. It also allows to see the different actors' perspective on the problem and to include more informal and subjective opinions, which in the authors' opinion can be beneficial for the project, if emphasised when occurring. The experts are likely to have an agenda that they wish to push in an interview (Kvale & Brinkmann 2009: 167) - the authors, as interviewers, are aware of this fact and the confrontations with different perspectives allow us to be critical of it.

Because of the differences in the subjects' backgrounds, two separate interview guides have been created. The interviews have been preceded by extensive literature study on the feed-in support schemes and other policy tools to promote biogas, as well as the use of secondary inputs for biogas production and the historical perspective on biogas in Germany. The interviews have been held in a semi-structured fashion, using explorative approach. Due to the ultimate aim of the interviews being to gain knowledge of the field, the questions are formulated in as direct and unequivocal manner as possible, but for the same reason, it was an aim to critically follow up on the replies and remain open to discussing issues not initially highlighted.

The subjects are two stakeholders connected to the biogas industry: Bruno Sander from the Danish Foreningen Biogasbranchen and Frank Hofmann from the German Fachverband Biogas. It was also an intention to speak to European Biogas Association about the EU's role in the legislation, but the attempts to come in contact with them have not been successful.

Bruno Sander

The first subject is Bruno Sander from the Danish Biogas Business Association (Danish: *Foreningen Biogasbranchen*). Bruno is the "professional director" at the organisation and he is responsible for updating industry stakeholders on policy development, serving as a link between the industry and lawmakers in his work with politicians and lobby work.

The aim of the interview is to gain general insight into the biogas industry. More specifically, the intention is to learn about the influence of the different policy instruments (such as feed-in tariffs) on the industry and the association's evaluation of these. Furthermore, we hope to uncover the perspective on the developments of biogas industry in Germany through the eyes of an outsider. The reason it was important to talk to Bruno despite him not being an expert in German biogas affairs was to not rely entirely on an account from a person directly working within the German biogas industry. In a way, the interview with Bruno Sander has been an introduction to the following interview.

Frank Hofmann

The second interview subject is Frank Hofmann, a specialist in international affairs of German Biogas Association (GBA, German: *Fachverband Biogas*). GBA is represents primarily operators and manufacturers of biogas plants in German and has around 700 members. Frank has directly worked with transition from energy crops to secondary resources as inputs for biogas production.

The purpose of this interview was to gain insight into the German biogas industry to confront the organisation gathering biogas-related stakeholders in Germany with the issue of unsustainability of the inputs. Frank was asked about the barriers for popularising secondary resources feedstock, whether the issue of low methane yield is on the agenda, the remuneration system in Germany and its importance for secondary inputs and for his take on what can be done for further expansion of the biogas industry in Germany. The interview serves directly as an empirical input for chapter 7.

Project Cycle Management

The Project Cycle Management (PCM) is used as a background measure of the contextual relevance of this report. PCM is widely used as a tool for development planning, especially by government agencies, such as the European Commission, but also non-governmental organizations (Golini et al. 2017). Advantages of using the model include the reflection of decision-making and implementation process, a clear definition of start and finish, responsibilities and well defined management activities (EC 2002). Since the planning method is used by many, variations of the phases in the model has occurred. This will however not affect this project since the research scope of this report is situated in the connecting point between the evaluation of a former or completed project and the initiation of a new project. Here, the expansion of biogas production in Germany is seen as the "project" that is to be evaluated, and a new problem in the shape of effective framework measures, localised not only in Germany, but on a larger scale, is attempted to be identified. For practical reasons, it is not possible to follow this project through the cycle of the model.

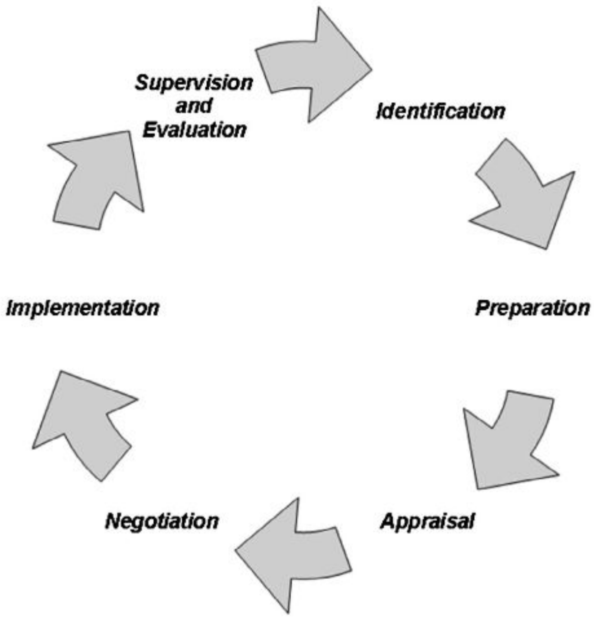


Figure #7: The PCM model (Golini et al. 2017).

Analysis strategy

For the sake of transparency, the analysis will be divided into two parts. The "input" part, where issues related to the inputs for biogas production are discussed, and the "output" part, where the products and potential uses of the products are discussed in terms of how this can contribute to the developments. The analysis is illustrated with the model below:

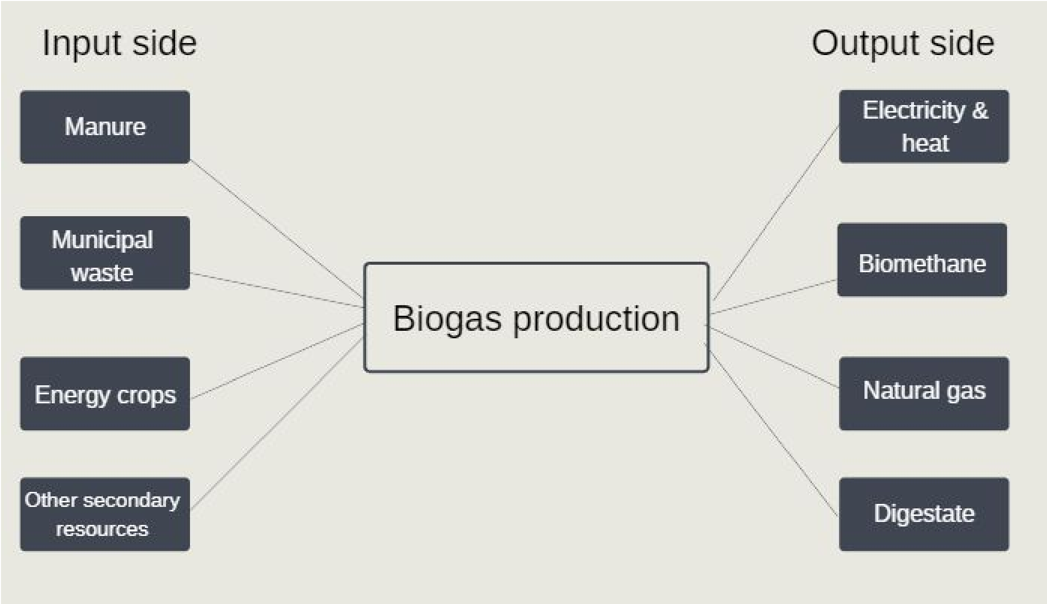


Figure #8. Structure of the analysis divided into two sections where each category represents the input side or the output side of the biogas production. Own work.

This is done as a means to explore each of the input and output categories included in this report and elaborate on the way they affect the process in relation to each other. The analysis will then be anchored in a systematic approach and, when discussing the design related to inputs, not go further into the specific detail of the production itself, such as practical or technical issues of the biogas plant e.g. the size of the reactors or construction of the receiving area.

Theoretical background

The project uses two main theories: Circular Economy (CE) and Multi-Level Climate Governance (MLCG). CE approach is the foundation of the premise of the project; reuse and circulation of resources is the target of the changes that are advocated in the project and the theory will be used throughout the project as a theoretical basis for all considerations. MLCG will be used in the final part of the project for discussing a policy recommendation for the EU; the theory advocates the involvement multiple stakeholders across levels and it will help us structure the competencies of each group and filter out actions that are irrelevant for the EU-level governance. The theories are described in detail in chapter six - Circular Economy and MLCG.

Scientific approach

Critical realism

This project employs the critical realistic approach. Critical realism was developed by English philosopher Roy Bhaskar, and describes the relationship between natural and social worlds. Its premise is that the reality exists independently of social systems and scientific developments and theories. It is also based in the idea that gaining knowledge is not uncovering an unchangeable structure, but dynamic relationships between humans and socially designed structures that is constantly changing (Jespersen 2003). In critical realism, there is not one universal scientific method; it is the characteristics of the research subject that is defining for which method the researcher should use. For that reason, a description of the research field is a prerequisite for gaining new knowledge about it. In critical realism, scientific research can be divided into three domains:

- the Domain of Empirical - where the data is observed and experienced
- the Domain of Factual - where data can be calculated with statistics and regularities
- the Domain of Real - which consists of non-cognisable elements that cannot be limited to quantities but can be attempted to be described qualitatively (ibid.)

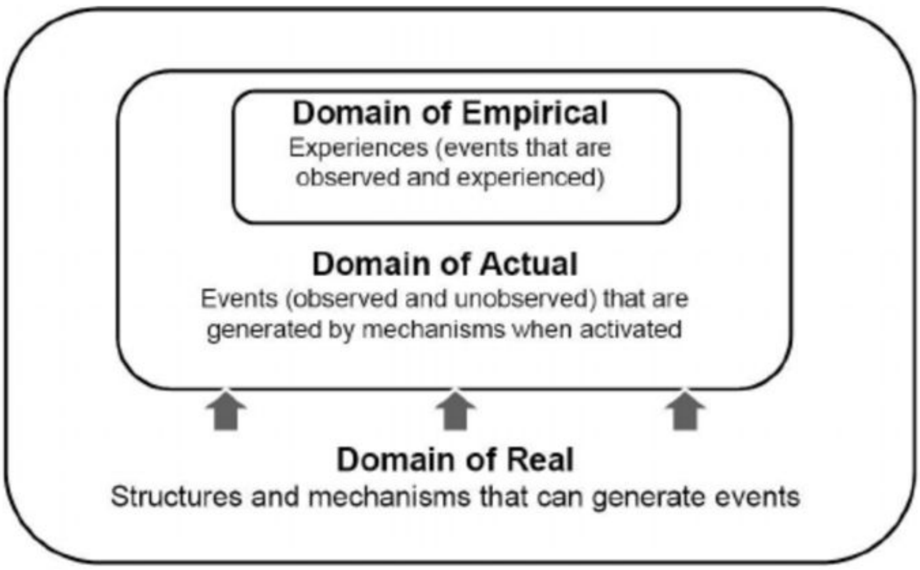


Figure #9: Three Overlapping Domains of Reality in the Critical Realist Ontology (Mingers 2004).

Since the Domain of Real is not quantifiable, the possibilities to describe it are very limited. For that reason, critical realism assumes that every research will include a degree of uncertainty of the ontology of the subject (Jespersen 2003).

This has methodological consequences for the project. The empirical domain is represented in the project by the interviews and how the interview subject experience the current biogas situation in Germany and Europe. The actual domain is represented in the literature and data e.g. on the current situation in Germany. The aim of the project is placed within the Domain of Real, which is expressed by the relation between the structure and mechanism of support schemes for biogas and its actual effect in the reality. The target of the project is to influence these event-generating mechanisms and since the consequences of this influence cannot be determined from quantitative data, the project seeks to understand these structures qualitatively using the example of a single case - Germany. Because the conclusions of the project are largely rooted in a specific context, the results are imprinted with a large degree of uncertainty and thus not generalisable; it is not possible to define the interactions between all actors and stakeholders and there is not one single solution. The results of the project are based on the attempt to understand the general mechanisms and should be understood as such.

Chapter three: Technology of biogas

Background section about biogas

This chapter will shortly present the anaerobic digestion technology with its pros and cons as well as perspectives and barriers for biogas usage. This chapter serves as the TSA dimension fulfilment (See: chapter two/dimensions).

Anaerobic Digestion technology (AD)

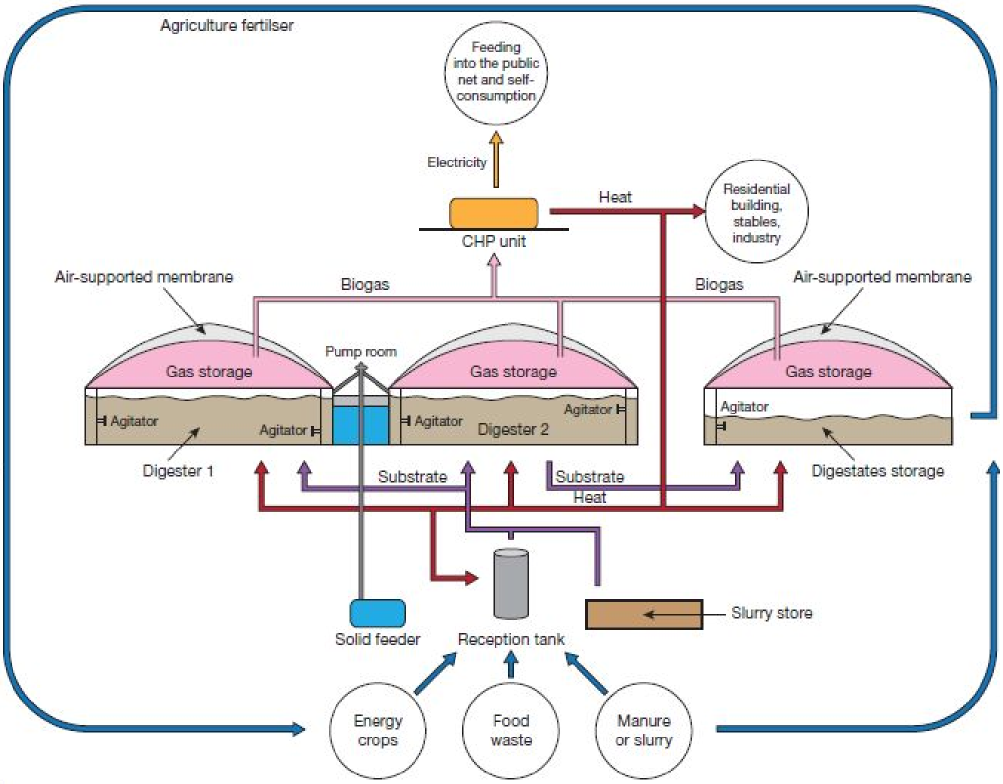


Figure #10: An example of a biogas plant with key components like receiving area, digesters, use for biogas and storage for digestate (Pullen 2015).

Biogas plant is a notion describing the closed environment designed for the process of *anaerobic digestion* to take place. First uses of anaerobic digestion have been dated back to 10th century BC in Egypt, and the industrialised version in India in 1859 (Nizami 2012). The system can take many forms; biogas plants can be made of concrete, steel, brick or plastic, and can be shaped as silos, troughs, basins or ponds, placed under the ground or on the surface (Demirbas & Ozturk 2005; Nizami 2012). The overall function is the same and all system designs share the main components of a premixing area/tank, a digester vessel, a system for using the biogas, and a system for distributing or spreading the effluent and digestate. The key component is the air-tight container with anaerobic conditions suitable for biogas production. The process and the input can be continuous or batch-typed. In a continuous process the organic material is constantly or regularly being fed into the digester without the interruption of unloading of output and reloading of input. Though the batch-digester is the easiest to build, a continuous digester can, when the design, operation and maintenance is well performed, make the production suitable for large scale production and provide a stable output of usable biogas (Demirbas & Ozturk 2005). The temperature can also affect the amount of biogas yield. For example, a thermophilic process, that occurs at somewhat higher temperatures (55°C), can eliminate more pathogenic (disease-producing) bacteria and decompose and produce biogas at a faster rate, but at the same time is much more sensitive to changes in temperature or input materials and close to a destruction of natural bacteria in general if temperatures get too high (Demirbas & Ozturk 2005). The process that is most commonly used in Europe, is the mesophilic process at lower temperatures of around 37°C (87%) (Nizami 2012). These digesters are less sensitive but also larger in size (Demirbas & Ozturk 2005). Other factors like pH, water/solids ratio, carbon/nitrogen ratio, mixing of the digesting material, particle size of the digested material and retention also have an effect on the biogas yield and the rate of production of biogas (ibid.).

Biogas

The biogas is produced through four stages of the digestion process: hydrolysis, acidogenesis, acetogenesis and methanogenesis (Nizami 2012). The process involves microorganisms decomposing organic material that other organisms turn into organic acids. These organic acids are further turned into methane by anaerobic bacteria (methanogens) and what is left is the stabilised slurry suitable for fertiliser (Demirbas & Ozturk 2005). The extraction of the gas also reduces the odour of the digestate product radically (ibid.). Biogas consists mainly of methane and carbon dioxide, but also of other gasses (see table below).

Table 1.1 Typical composition of biogas

Component	Concentration
Methane – CH_4	50–75 volume – %
Carbon dioxide – CO_2	25–45 volume – %
Water vapour – H_2O	2–7 volume – %
Oxygen – O_2	<2 volume – %
Nitrogen – N_2	<2 volume – %
Ammonia – NH_3	<1 volume – %
Hydrogen – H_2	<1 volume – %
Hydrogen sulphide – H_2S	20–20,000 ppm

Source: Sustainable Energy Authority of Ireland, 2013

Figure #11: Composition of biogas (Pullen 2015).

Biogas coming directly from the digester burns at a relatively low temperature, as its moisture and low pressure prevent it from reaching higher temperatures. The gas is consequently dried to a moisture content below 2 % and other gasses or impurities are sorted out.

The upgrading and use of biogas

Aside from using the biogas as an energy source, it is also possible to "upgrade" it by extracting pure methane from the biogas. Methane has the same chemical structure as natural gas which makes it suitable for injection into the gas grid for use as e.g. cooking or as a fuel for vehicles (Pullen 2015). Biogas, consisting of CH_4 (methane) and CO_2 (carbon dioxide) is upgraded through removal of carbon dioxide; in order for biogas to be used as fuel, further removal of hydrogen sulphide is required, as it forms sulphuric acid when burned and therefore is toxic (Nizami 2012; Melville et al. 2014). The cleaning of the biogas is performed through processes such as scrubbing, adsorption, absorption and drying, among other techniques (Deublein & Steinhauser 2008). A clean methane end product has a greater energy value than the mixed biogas. One cubic meter (m^3) of methane has the energy potential of approximately 10 kWh (9,97 kWh) or 36 MJ, compared to the energy value of *biogas* with a methane content of e.g. 55%, where one cubic meter can provide the energy of 5,5 kWh or 21 MJ (Pullen 2015). Heat and electricity can be produced when burning the methane by a combined heat and power engine (CHP) (Melville et al. 2014; Pullen 2015), a microturbine (Nizami 2012) or induction generator and surplus electricity can be transferred on to the local electrical grid (Nizami 2012; Demirbas & Ozturk 2005) after being used on place e.g. to maintain the operating of the plant (Melville et al. 2014). Though the upgrading process is relatively expensive and requires large amounts of energy, it is relatively widespread in countries like Sweden, where biogas is available for purchase at petrol stations (Jørgensen et al. 2008).

Digestate

A by-product from biogas production is digestate. Digestate is the digested de-gassed remaining of the input material. It is rich in nutrients, as it retains all the nutrient content from the input material and, as such, it is largely used as an organic fertiliser in agriculture. Depending on the source of the input of the digested material, usage of digestate can have a number of advantages. Generally, digestate as fertiliser partly replaces the role of synthetic fertilisers, which additionally can reduce the CO_2 emissions linked to the production of synthetic fertilisers (Lukehurst et al. 2010). When the input material is digested in a biogas plant, the content of organically bound nitrogen is reduced and a larger amount of nitrogen to be absorbed by the plants is possible. This reduces the amount of organically bound nitrogen in the soil and thus rate of nitrate leaching (Wang et al. 2019). Application of digestate also allows to recover phosphorus, which is a nutrient that is likely to be scarce in the recent years. Phosphorus recovery is otherwise difficult and anaerobic digestion process allows a relatively simple way to recirculate the nutrient. Research has indicated that the uptake of both phosphate and nitrate from the digestate is similar to the uptake from mineral fertilisers (Lošák et al. 2014), though it has been suggested that the solid fraction has a higher concentration of phosphorus, suggesting that separation of the solid and liquid fraction might be beneficial (Bachmann et al. 2016). Manure as the input gives an additional benefit of GHG-savings from manure storage (Lukehurst et al. 2010), that is otherwise usually stored in open silos and emits large amounts of both CO_2 and CH_4; anaerobic digestion process allows to capture those gases. As mentioned earlier, the digestion process also removes most of the odour of the input material and can be a means to sanitate the manure and remove the possible pathogens and weed seeds.

Some research has showed that digestate application can increase the agricultural yield (Šimon et al. 2015), but other research showed conflicting results (Przygocka-Cyna & Grzebisz 2018), also pointing out that application of digestate can enhance the accumulation of heavy metals and certain elements, such as cadmium and lead in plants (ibid.). The nutrient content in digestate also varies considerably, dependent on the input material (Risberg et al. 2017).

Biogas risks and challenges

Several risks of the operation of a biogas plant have been identified. Biogas is seen as a climate-neutral fuel (Reinelt et al. 2017), as the product digested is releasing carbon that has been absorbed from the atmosphere when growing. The fermentation of the digested material produces methane, constituting 50% - 70% of the biogas. Methane is a strong greenhouse gas with a global warming potential (GWP) of 28-34 times higher than the potential of the same amount in CO_2 (Reinelt et al. 2017). In case of methane leak, the environmental benefit could be lost. Methane spills can happen during the whole biogas production cycle: from manure storage prior to transporting it to the plant, during the transport, in the receiving hall and during the digestion process, but also during gas distribution and utilisation (Liebetrau et al. 2017). There is a number of measures that must be taken to minimise the emission, such as following the technical requirements for the digestate tank, frequent leakage control surveys or keeping the filling level of the storage well below 80% at all times (ibid.: 35). Further elaboration on the topic is not in scope of this project, but it is a relevant and necessary issue to consider for all biogas expansion projects.

The operation of a biogas plant also has a social challenge, considerations in relation to the STS dimension. This concerns especially the odour that can emerge when cleaning the tanks (Vanek et al. 2011), or other local disturbing factors, all which are not to be underestimated. It is an increasing problem that has been experienced when implementing other renewable energy technologies like solar panels and windmills and is referred to as NIMBY, an acronym for *Not In My Backyard*. The phenomenon has an enormous effect on the sector overall, since public recognition is of importance for the opening of the way for expansion of a technology, mainly concerning practical issues. The HuffPost calls NIMBY a social construction as opposed to a natural phenomenon, and it needs to be addressed: *"It is a* *predictable and at times appropriate response to inappropriate development or development that has been undertaken without adequate community engagement."* (Cohen 2016). For this reason, it might be necessary for the municipalities to develop strategies to meet citizen complaints in advance and emphasise the importance of dialogue with the local communities. In case of biogas created from energy crops, the phenomenon of landscape maizification is also considered a factor that can be of relevance to the sector being recognised by the public and is also in relation to STS - this issue is further elaborated on in Chapter five.

Chapter conclusion

This chapter has explained the functioning of anaerobic digestion technology and highlighted the following possibilities for use: biogas can be used as a fuel for energy and heat, as biomethane in transport sector and natural gas grid, whereas digestate has a number of environmental advantages when applied as fertiliser in agriculture. Certain challenges are identified in a holistic perspective to not underestimate the importance of including the sector of the civil society.

Chapter four: Support schemes

This chapter will briefly present the concept of state-driven support schemes that promote investments in renewable energy and biogas in particular. As identified, these mechanisms, and especially Feed-in Tariffs, are the most significant reason for the initial increase and later decrease in the development rate of biogas investments in Germany; the particular case of Germany is presented in detail in chapter five: Germany, renewable energy and biogas.

The aim of the policy mechanisms set up to accelerate investments in renewable energy is to secure the profit for the investor. Such policy mechanisms can take a variety of forms, the most common and the most widely used (Couture et al. 2010) and effective (Klein et al., 2008; Mendonça, 2007; IEA, 2008) being the Feed-In Tariffs (FITs). There are typically three prerequisites of FITs. The energy producer needs to have a guaranteed access to the grid, that is, be able to sell their energy at any point in time (Mendonça 2007). Secondly, the purchase agreement must be stable and long term, typically about 15-20 years (ibid.). Finally, the payment levels are based on the costs of energy generation, either specific for the technology used or for renewable energy in general (ibid.). In Germany, additional benefits for the energy producer include lessening the burden of bureaucracy, shortening waiting time for project approvals or minimising project costs (Couture et al. 2010). In most countries, virtually anyone is eligible to invest and draw benefits from FIT policy, including private persons, business owners, state agencies and other organisations (ibid.). In most cases, feed-in tariffs are designed to work with electricity prices, but in a few cases also other types of energy. Countries such as Austria, Estonia, Finland, and the Netherlands have implemented Feed-in Premiums in the heating sector, while the transport sector uses fuel quota rather than FITs (EC 2016a). In the EU, there are only two Member States (Cyprus and Malta) that do not employ support schemes for electricity from biogas, but in heat and transport sectors there are respectively 10 and 12 countries that do (EC 2016a).

Feed-in tariffs can be funded in a variety of ways. Germany uses the ratepayer approach, where the added incremental costs are directly included in the rate base (Couture et al. 2010), in the Netherlands, it is funded by public taxes and in Spain by a combination of these two approaches (ibid.). Other ways for funding FITs can be e.g. carbon auction revenues and utility tax credits (ibid.).

An effective FIT policy should be designed to cover the cost of the investment plus an additional profit, so the investment is safe to return to the investor, independently of the fluctuating energy cost, which otherwise makes investors reluctant to invest in energy technologies (Klein et al. 2008; Couture et al. 2010). The FITs amounts might be dependent on the market price of electricity, but it is not necessary; a market-dependent FIT, also called a fixed-price FIT payment, is independent of the market kWh price of electricity, whereas the market-independent FIT, also called premium FIT payment, or *feed-in premium* the payment is an extra payment on top of the market price (Couture et al. 2010). The first option is likely to be advantageous for the investor, as the stable investment conditions might be reflected in lower project financing costs (Couture et al. 2010; Fouquet & Johansson 2008). Premium payment should principally be designed so that the total income slightly exceed the energy generation cost; it can either take form of a constant payment, where the premium is fixed, or sliding, where it moves with the fluctuating market price (Couture et al. 2010). Constant premiums are the easiest to design, but there is a risk that the investors will be unwilling to participate due to the concern that energy prices might drop below the level where it would be beneficial. Fluctuating premiums can, again, take a variety of forms; in Spain, for example, the rate is determined on an hourly basis to ensure that the payment rises and declines as the price of electricity fluctuate.

Typically, a FIT payment will be differentiated by a number of factors. First and most the basic determinant is the technology used for energy production: payments for e.g. solar energy and biogas will be different, since the generation costs are different for those two technologies and there might be an agenda to prioritise one of the technologies over the other (Couture et al. 2010). Payment might also be differentiated by project capacity: larger generators are typically offered lower payments to account for economy of scale. Payments can also be differentiated by resource quality or location, e.g. offshore wind energy.

FIT payment levels can also be adjusted for a number of other factors; inflation is a very typical example. The notion *degression* refers to the payment reduction as the technology develops and the energy production costs are getting lower. This can be tackled through a pre-established tariff degression, where cost reduction is basically forced upon the project and responsive tariff degression, in which the rate is lower along with general market prices for energy. There is also a payment setup known as front-end loading, where the project is divided into two parts: the initial period where the project is set up and the costs are the highest, due to the need to establish infrastructure etc. and the period afterwards, where the project is already running and the payment is subsequently lowered (Couture et al. 2010).

FITs can be also adjusted with bonus payments for a variety of factors: use of certain inputs, such as manure for biogas in Germany, but also repowering of old energy projects, high efficiency etc. This can be of special relevance for biogas projects that could be incentivised to use secondary resources. The figure below shows the overview of FIT policy design options:

FIT Payment Levels				
Design Options		**Notes**	**Fixed***	**Premium***
Price setting based on (one of the following):	Cost of generation	Determined in relation to the actual cost of developing the technology, plus a targeted return.	X	X
	Value to the system	Based on either time of delivery, avoided costs, grid benefits, or other supplementary values.	X	X
	Fixed price incentive	Fixed payment level, established without regard to RE generation costs or to avoided costs.	X	**
	Auction-based price discovery	Periodic auction or bidding process, which can help set technology- and/or size-specific FIT payment levels	X	**
Payment differentiated based on (one or more of the following):	Technology and fuel type	Tailors the FIT policy to target desired technologies and/or fuel. Payment levels broken out to recognize differences in cost, by project	X	X
	Project Size (kW or MW)	Helps stimulate both large and small projects by offering different prices for each. Lower payments are awarded to large generators to account for economies of scale.	X	X
	Resource quality	Can be used to limit windfall profits and dispersing projects and benefits across jurisdictions.	X	**
	Location (or application)	Can help target specific applications such as rooftop PV or offshore wind energy.	X	**
Ancillary Design Elements (one or more of the following)	Pre-established Tariff Degression	Pre-determined downward adjustments (typically annual) for subsequent projects to track, and encourage, cost reduction	X	**
	Responsive Tariff Degression	Enables the rate of market growth to determine the future rate of degression, and thus, the future FIT payment level	X	**
	Inflation adjustment	Protects the real value of RE project revenues from changes in the broader economy (i.e. CPI)	X	X
	Front-end loading	Higher tariff for an initial period, replaced by lower levels afterwards; helps financing.	X	X
	Time of Delivery	Tiered payment levels according to times of high and low demand (by day/season); encourages market-orientation	X	X
Further differentiated with bonus payments to encourage:	**High efficiency** systems (e.g. cogeneration), use of specific **waste streams** (e.g. farm wastes, municipal wastes, construction and demolition waste, etc.), **physical location of systems** (e.g. building-integrated), **repowering** of old wind and hydro-electricity projects, certain **ownership structures** (e.g. community-ownership), use of innovative technologies, etc.		X	X

Figure #12: Overview over design options for a FIT policy (Couture et al. 2010).

Chapter conclusion

This chapter has presented a variety of solutions for design of a FIT policy. Here, it is highlighted that there are several parameters that the lawmakers designing a policy must address, which means that there are unlimited possibilities for creating different incentives with different mechanisms within the policy. The presented solutions are examples that have been implemented in Europe. Principally, it is possible for policymakers to design a FIT from scratch. In this project, a detailed FIT policy will not be designed, but the principles and possibilities of the concept will be used in chapter eight to validate the conclusion.

Chapter five: Germany, renewable energy and biogas

This chapter will present the case of Germany as the largest producer of biogas in the EU. The aim of the chapter is to (1) describe the current state of biogas in Germany, (2) present the historical perspective of biogas development and determine the role of FITs for the German biogas industry and (3) map the potential of secondary inputs for a potential transition from energy crops.

Germany is by far the largest producer of biogas in Europe (Scarlat et al. 2018b). Out of over 17,400 biogas plants of all sizes and capacities in Europe in 2015, over 10,000 were in Germany (ibid.) (see figure #13).

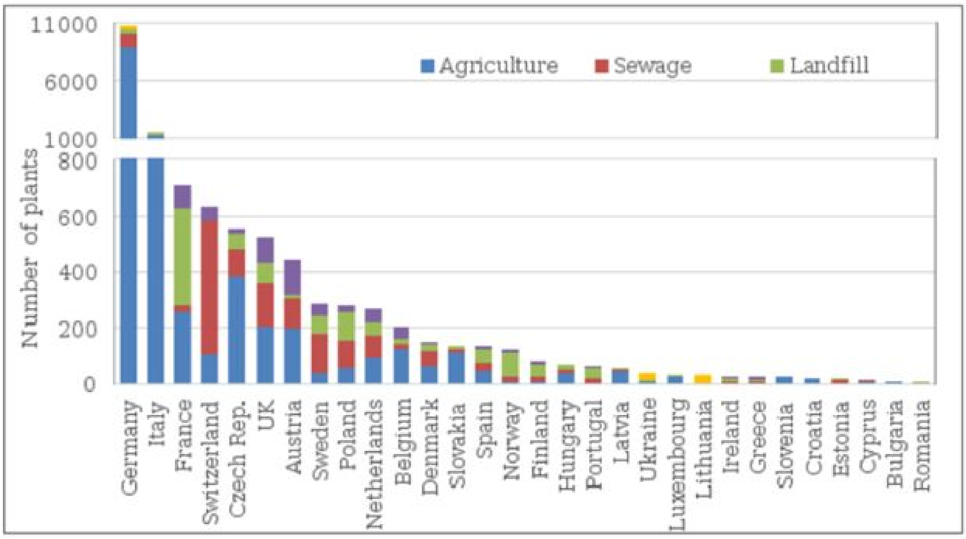


Figure #13: Number of biogas plants in Europe in 2015 (Scarlat et al. 2018a, based on EBA 2016).

In terms of the total primary energy production from biogas in EU, Germany stood for roughly a half of it; total primary energy production in EU was estimated to exceed 653,636 TJ, while Germany produced 328,840 TJ of it (Scarlat et al. 2018a). This is likely due to the fact that German biogas plants have usually a smaller capacity, as they are often operated by local small farmers that look for an additional income source (de Graaf & Fendler 2010).

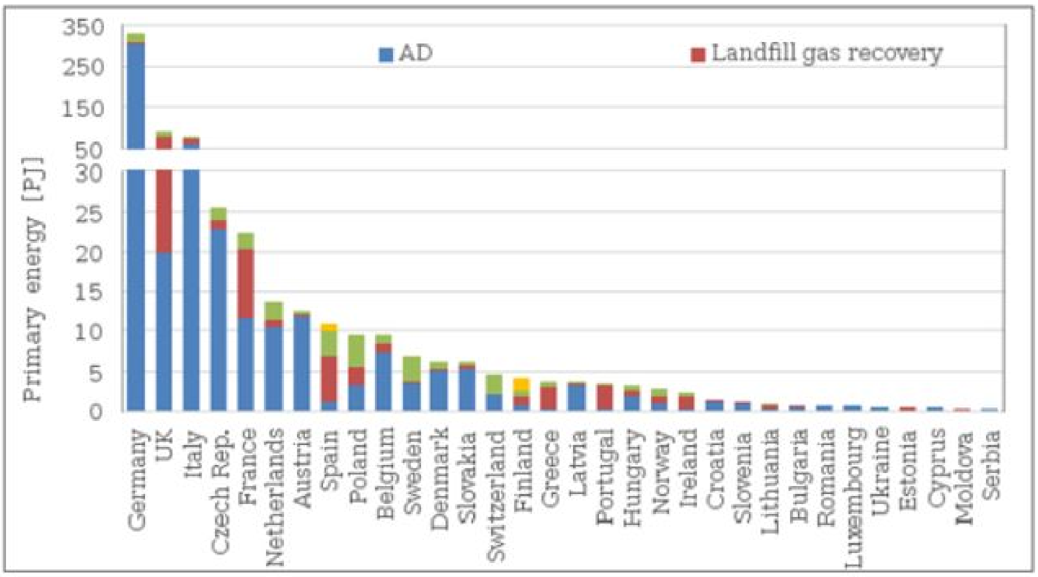


Figure #14: Primary energy production from biogas in Europe in 2015. Source: Scarlat et al. 2018a, based on Eurostat 2017.

Renewables constitute roughly a third of Germany's total energy production. In 2018, 35.2% of total gross power produced was renewables. Biomass is a meaningful, but not crucial energy source in the country, though it makes up a large part of total energy production from renewables. Approximately 20% of power production from renewables was constituted by biomass, which corresponds to 7% of total power production.

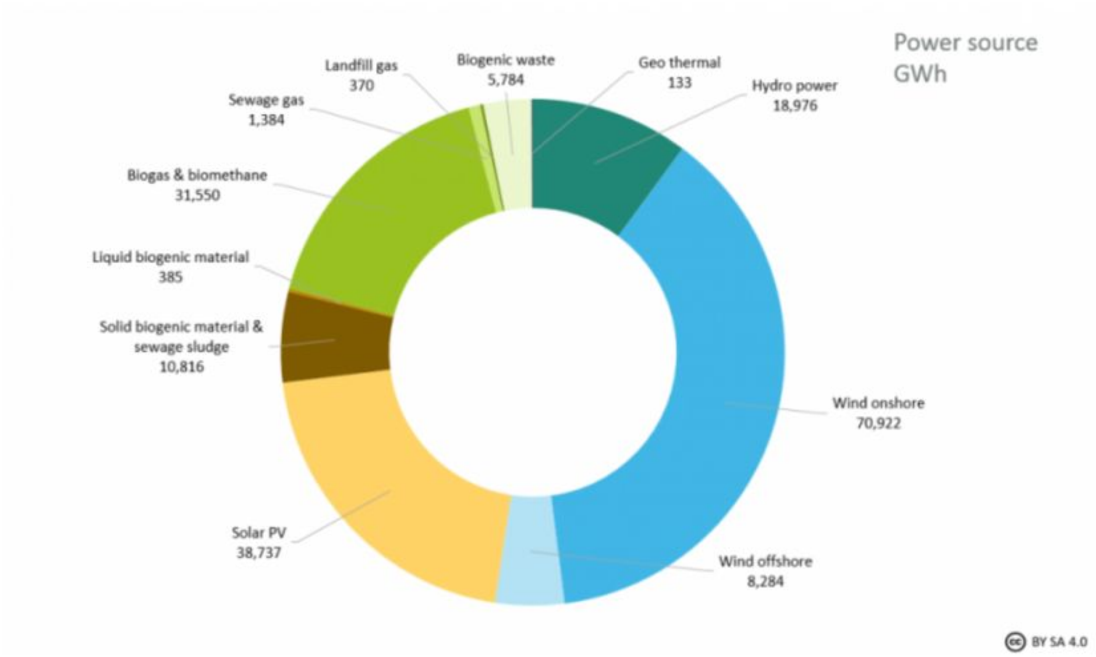


Figure #15: Germany gross power production from renewables in 2015 (https://www.cleanenergywire.org/factsheets/bioenergy-germany-facts-and-figures-development-support-and-investment).

Biogas plants constitute the majority of Germany's bioenergy sector (Appunn 2016). The most of the energy produced in these plants is fed into the grid as electricity or used to generate heat for local heating networks. In some cases, the biogas is upgraded into biomethane and subsequently fed into the natural gas network (Apunn 2016). Further properties and uses of biomethane have been described in chapter three. According to the German Biogas Association, there are currently over 200 active biomethane plants in Germany (GBA n.d.). Most biogas installations are located in southern and northwestern Germany (AEE n.d.). As of 2018, in the states of Bavaria and Lower Saxony, the capacity amounts to 1360 MW and 1358 MW, respectively. Apart from the small state of Saarland and urban areas of Berlin, Hamburg and Bremen, as well as the state of Rheinland-Pfalz (where total capacity is 90,1 MW) the total capacity in every German state is larger than 100 MW (AEE n.d.).

Biogas in Germany, a historical perspective

The anaerobic digestion technology has a long history in Germany. The modern biogas technology was first introduced on a larger scale at the turn of the 19th and 20th century, mostly motivated by the necessity to sanitise wastewater and protect drinking water (Pfeiffer & Thrän 2018). First large-scale wastewater digesters were built in 1910s and '20s, and immediately after, a gas net was built to distribute biogas and convert it to electricity and heating. Over years, through the ups and downs of German history, the technology had been developing; after World War II, agricultural biogas plants have been developed and the first one opened in 1948 in West Germany. In the GDR, the development was slower and first industrial-scale biogas plants opened in the 1980s. Following the German reunification, a law on feed-in tariffs (FITs), promoting investments in renewable energy was introduced in 1991; this was the milestone of the German energy transition (ibid.). In 2000, a series of laws called Erneuerbare-Energien-Gesetz (EEG; eng. The Renewable Energy Act) were passed (Bensmann 2010). EEG was motivated by the need to reduce the demand for fossil fuels, but also as a reply to the agricultural overproduction in Europe. The EEG introduced a FIT scheme, the aim of which was to encourage investment in renewable energy (ibid.). FITs are further described and characterised in chapter four. The EEG and its FIT scheme facilitated the rapid growth in the number of biogas plants in Germany. The number of biogas plants grew from 1050 in 2000 to over 8000 in 2011 (Statista nd.a). Since 2000, the EEG has been revised several times; the growth rate varied in accord with those revisions. The development between 2000 and 2004 was slow and steady, then stagnated slightly until 2009 when it exploded like never before. According to Apunn (2016), the first boom is due to the 2004 revision that increased tariffs for bioenergy and bonus for renewable primary input products, and the stagnation happened *"because everybody was waiting to see what the new law would offer in remuneration"* (Apunn 2016), and indeed the rules introduced with the 2009 reform made bioenergy even more beneficial for the investors with the surcharge being raised from 0.54 ¢/kWh to 1.32 ¢/kWh (BMWi 2014). The fourth EEG, amended in 2012, introduced stricter rules for generation of electricity from biomass and, despite further growth in surcharges, the boom stopped suddenly in 2013 (Pfeiffer & Thrän 2018). The following year, 2014, introduced what is called the EEG 2.0. This was the first EEG that took a sharp policy turn and dropped the FIT model altogether, introducing the market premium model instead (Dotzauer et al. 2018).

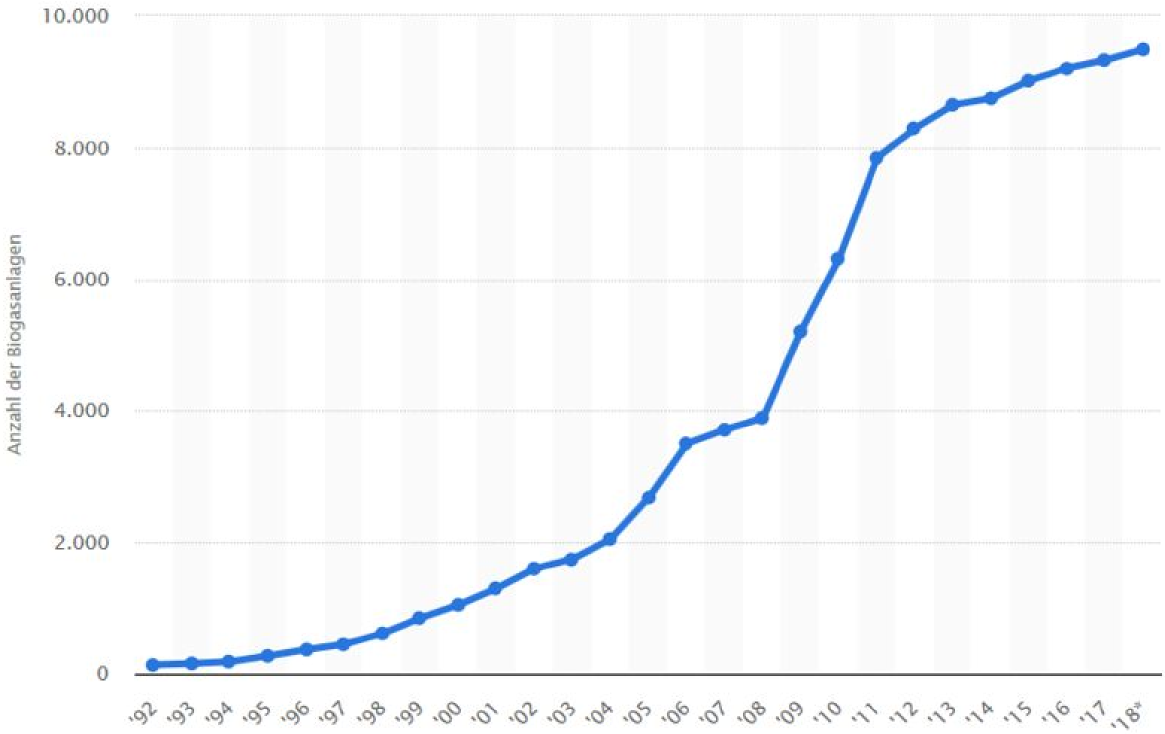


Figure #16. Number of biogas plants in Germany between 1992 and 2018. (Statista nd.a)

Under the new rules, instead of a fixed tariff, the operators receive a market premium from the grid operator that compensates the difference between the EEG payment and the average spot price for electricity (BMWi 2019). Moreover, the support for biomass energy was cut considerably (FNR n.d.) and a limit of 100 MW was set on new biogas plants (Apunn 2016). A number of factors played a role in this decision. Firstly, the public support for biogas was very volatile; biogas plants in Germany rely mostly on energy crops, such as maize, turnip, whereas manure is only a secondary input (Appunn 2016). In some parts of the country, the demand for organic inputs for biogas production has been so large that significant amounts of agricultural land have been “maizified”, the large monocultures being a threat to ecosystems and visually unappealing. Energy crops started appearing in grasslands, that had been biodiversity hotspots. Around the same time, heavy use of wood pellets for energy productions in the UK have negatively influenced the reputation of bioenergy in general (Appunn 2016). Secondly, the sole purpose of the feed-in tariff scheme, price digression, was very insignificant in comparison with other technologies, such as wind and solar power.

Biogas remained one of the most expensive power sources (Apunn 2016). Since 2014, the growth in the number of new plants has been steady, but slower than ever.

Inputs for biogas production in Germany: Status Quo

According to Daniel-Gromke et al. (2018), German biogas plants are largely operated within the agricultural sector; manure and energy crops completely dominate the inputs, accounting for around 92% of all inputs, and this is largely due to the bonuses that the EEG provided for usage of these (Daniel-Gromke et al. 2018). Looking at mass, energy crops constituted 51.2% of inputs and animal excrements (manure) 41.4%, but due to lower methane content of manure, energy crops constitute 78.3% of the input energy-wise (ibid.). Utilisation of food waste and other waste compounds from households, industries and agriculture constitute a very little part of the inputs total and biowaste and industrial organic waste are used in less than 3% of the plants as of 2015 (Daniel-Gromke et al. 2018).

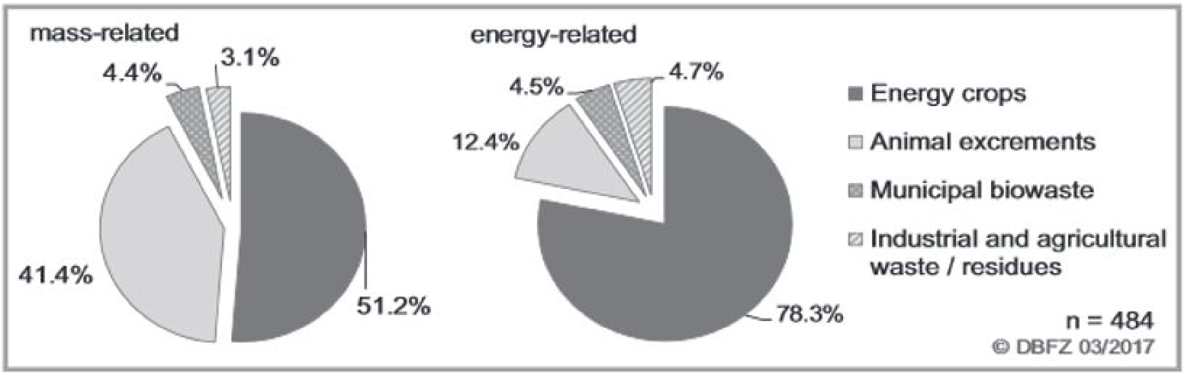


Figure #17: Substrate input in biogas plants (DBFZ Operator survey 2016 via Daniel-Gromke et al. 2018; reference year 2015).

This could question the basic goal of this project: is it possible to increase the rate of development of biogas while only relying on secondary resources and limiting the use of energy crops? German Biogas Association expresses the following in a special note:

"The amendment in 2004 was also very important because the bonus for renewable primary products had given the biogas sector a vast impetus. 'We had proposed the bonus at that time, because we were running short of waste input. The number of biogas plants fermenting

commercial kitchen and food industry waste was rocketing after the first EEG. The plants were depriving each other of residue materials and as a consequence, many biogas plants were running only at part load', Josef Pellmeyer, president of Fachverband Biogas e.V., and a biogas producer himself, explains the situation." - Bensmann 2010

Pellmeyer claims that biogas industry cannot rely on waste residues alone, as during the boom years the plants could not run on their full capacity, and there needed to be made changes in the proportions of inputs. But the possibility that waste inputs can be collected more efficiently and utilised in a larger scale is still to be investigated.

Chapter conclusion

It has been explain how the FIT, among other factors, has been the main driver for biogas development in Germany. The consequence of the hasty development is an overreliance on energy crops which the German state needs to address in the near future.

Chapter six: Circular Economy and MLCG

The following chapter presents the theoretical background of the project.

Multi-Level Climate Governance

The transition towards a sustainable society is a complicated and comprehensive task. The mobilisation of different actors across different levels, both vertically and horizontally is its essential condition, but it is not easy to conceptualise. Jänicke (2017) presents a number of overall considerations to help understand the system that is referred to as a *"global framework creating opportunities for action and interaction."*, throughout this project referred to as the Multi-Level Climate Governance (MLCG).

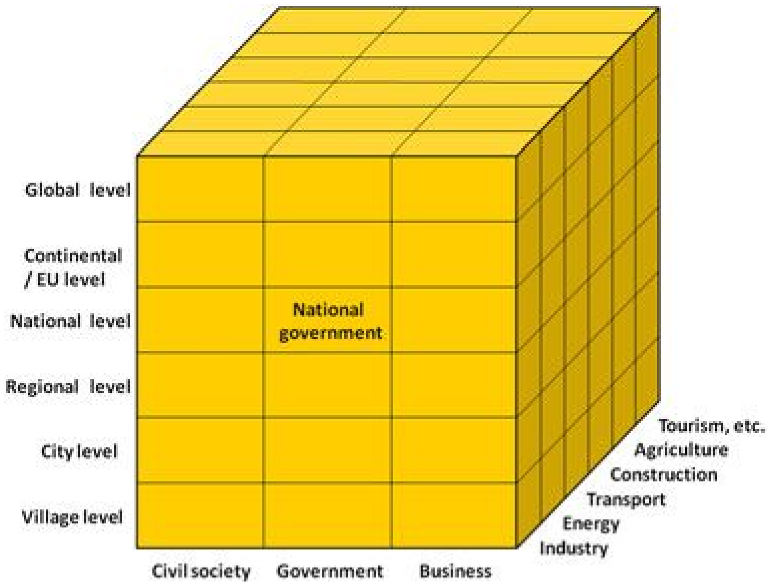


Figure #18. The "Rio model" that is visualising a multi-level and multi-sectoral governance system (Jänicke 2017).

The term "Multi-Level Governance" originated from the attempts to describe the structure of governance in the European Union, but has since been adopted for global governance by the United Nations. It is seen as an important tool arising with the need for mobilising global actors toward sustainability. The model originated from this standpoint, and it is emphasised that the function of the model is to create an opportunity structure, and that the opportunities should be met and supported by policies and regulations. A model of the global system called the Rio model was developed as part of the Agenda 21 plan at a United Nations summit in Rio de Janeiro in 1992. Two approaches have been practised since the development of the model, both using the same model as a starting point. The first approach which was used in the Agenda 21 plan was focused on goal-setting global governance across sectors and levels by involving not only government actors but also the business sector and the civil society. The model focused mainly on three levels, the global, national and local level. At a later summit in Johannesburg in 2002, the levels also got to include a regional level.

The model has since been used for other purposes, such as climate protection or green economy. In these cases, a second approach to using the model was used, creating a developed version of the model. This approach has, according to Jänicke, had other and more successful results than in the first original Agenda 21 context, since many of the suggested solutions have already been implemented. In the first approach the completion of the actions seemed limited as Jänicke expresses: *"This transfer of knowledge and policy from the global to the local level was remarkable. Its success, however, was restricted to agenda-setting and policy formulation; its implementation was significantly less successful (Bertelsmann-Stiftung, 2013)"* (pp.109). Jänicke describes that the main difference of the application of the model was that the Rio model at first was characterised as *norm-driven*, and when used in a climate governance aspect the approach was more *interest-driven*. As the Agenda 21 plan focused on making a coalition between the government and civil society, *climate governance* focuses on making industrial policies within a socio-technical system to induce dynamic development, horizontally and across levels and sectors. The interest-driven policies are characterised as evolving around a socio-technical system based approach, meaning that focus is mainly supporting climate-friendly or low-carbon technologies. This feeds what Jänicke also describes as an important factor of the MLCG, that a much larger focus on the *co-benefits* of an implemented policy is taken into consideration, namely economic co-benefits, but social and environmental co-benefits as well.

Economic	Social	Environmental
Energy security	Health impact (e.g. via air quality and noise)	Ecosystem impact (e.g. via air pollution)
Employment impact	Energy/mobility access	Land use competition
New business opportunity	(Fuel)Poverty alleviation	Water use/quality
Productivity/competitiveness	Food security	Biodiversity conservation
Technological spillover/innovation	Impact on local conflicts	Urban heat island effect
	Safety/disaster resilience	Resource/material use impact
	Gender impact	

Table 1. Possible co-benefits of climate protection (IPCC, 2014)

Climate benefit only	Multiple (co)benefits
Burden-sharing	More opportunity-sharing
Norm-driven	More interest-driven
Obligatory	More voluntary
Fixed targets	More dynamic targets

Table 2. Specifics of the co-benefit approach to climate governance

Figure #19: Examples of interest-driven and norm-driven approaches (Jänicke 2017).

This is, among other things, the factor that makes the sectors of civil society, government and the business sector relevant in the model structure. Most co-benefits of climate policies have though proven to be economic. Jänicke focuses on economic and technical change, as well as an increase in natural capital, and a change in lifestyles, societal norms and institutions, if other co-benefits should occur in a larger extent.

The levels of the model

Jänicke describes how global climate governance needs the concept and systematic understanding of Multi-Level Governance to use the premises and potentials of these observations:

1. Climate protection is a global problem, but global governance is dependent on intermediate levels.
2. Each level has its own responsibilities, and holds horizontal dynamics.
3. Vertical connection makes up-scaling of best practises possible.
4. Multi-sectoral dimension makes co-benefits possible.

The system allows government actors to grasp the opportunities for actions and interactions that can occur between the levels and sectors. This is visualised as connecting arrows that each are presented as enabling communication and the ability to influence other levels as going both ways (see figure #20).

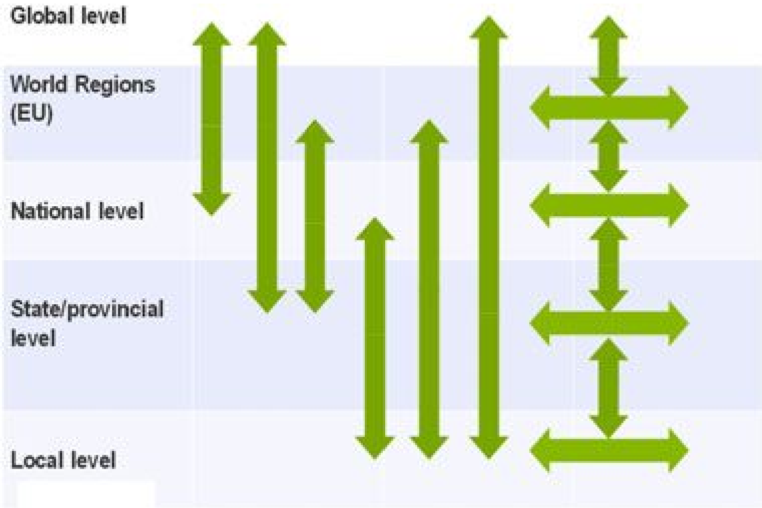


Figure #20: Potential horizontal and vertical interactions across levels (Jänicke 2017).

The MLCG is a model that seems to cover the concept of Multi-Level Governance as an expanded version that dynamically adapts to newly discovered aspects, e.g. emerging levels that grows increasingly important, as the following description of levels shows, but also the ability of adapting raising targets based on advancement.

The levels are important in their own position, and it is emphasised how the *polycentricity* of the system (that is, multiple governing authorities in different scales) is important. These horizontal and vertical levels interactively provide opportunities, such as climate-related innovation, *lesson drawing* (peer-to-peer learning), bottom-up harmonization (up-scaling of best practices) and top-down initiatives that potentially induces horizontal dynamics, reinforcing a global system of interactive learning and knowledge sharing, but also cooperation and competition. The levels specific role in the system are unfolded below:

The global level:

The main objective on the global level such as the UN is to act as a catalyst to generate activity and also to provide the knowledge-based influence and relevant information to actors at lower levels. The global level does not have a lot of direct power, but it is essential for underpinning the global consensus and necessary for global decision-making.

World regions:

World regions, such as the EU or the African Union, bring together common interests and problems of the region and translate the global goals into geographically specific cases. The *"institutional capacity of organized world regions"* has increased in the last few years, although they are radically different. The EU is exemplified as a strong case in relation to MLCG. World regions have the possibility to set own sustainability agendas or form partnerships with other world regions.

National level:

The national level is responsible for creating climate regulations that are to be implemented at lower levels, and is the most powerful level where climate policy leadership is strongest. It is the main focus of the public opinion (lower levels), has the highest level of legitimacy and also plays an important role internationally in a network with other countries or as promoting competition for e.g. clean energy.

Provincial or State level:

Sub-national regions play a role in the implementation phase of policies introduced by national states. Competition can also play a role on this level, especially in relation to the global market. This is also the level where co-benefits like job creations or business opportunities are emerging. These regions can also act as a competition with the nation-state if wanting more ambitious climate policies.

City level:

The city level is where national regulations and policies concerning e.g. transport, infrastructure and waste are implemented. Cities also *"have policies, plans, and targets to advance renewable energy, often outpacing ambitions of national legislation (…) Cities seek to share and scale up best practices (…) in turn, national governments often observe sub-national actions and consider using successful programmes as blueprints for national policies"* (REN21 2014: 86).

Rural local level:
The level of rural/local communities is of increasing importance for the practical execution of climate-related actions, e.g. by CO_2-sequestration, production and export of clean energy and experimenting.

Micro level/individual level:
This level represents voters, consumers and NGO members that are restricted in the way that any effect of this level may often be seen late in "the chain of causation of climate problems"; actors on the individual level are not the main source of solutions. The intervention that can be of importance on this level is the support for climate-friendly solutions already made, such as switching electricity suppliers or creating internet campaigns. They are seen as members of a global system as they refer to global climate problems, objectives and a global knowledge base.

Jänicke consequently emphasises that the national level plays a very important role, as it serves as the mediator between overall global goals and all the underlying levels and also holds a great power of mobilisation for all levels.

Accelerations and policy recommendations
The potential of the opportunities are generated and accelerated by action. These are not exclusive and can overlap or reinforce each other. Among lesson drawing and horizontal dynamics induced Jänicke mentions *mutually reinforcing cycles* and *lead markets* as policy related factors. With the leading market principle, there should within the national market be an incentive to create fundamentals for developing a leading market for low-carbon technologies, that can reach a level to enter the global market and in a later perspective will be able to provide returns on what he calls learning costs. This meaning that there should be a certain free scope within the national boundaries to innovate and develop clean energy technologies. By mutually reinforcing cycles he means that a positive feedback can be created by unexpected success, and increased learning of technologies and interaction between clean-energy markets induced by policies. He also describes how new interest and capacities can arise as a consequence of this.

The considerations and experiences of the model concludes into these policy recommendations:

1. Use the dynamic potential of the multi-level system, translate and communicate the co-benefits of the policies.
2. Raise ambitions in cases of success, set dynamic targets based on learning-by-doing (as he also mentions is included in the Paris Agreement).
3. Support horizontal networks and coalitions, increase the capacity of the system at each level.
4. Focus especially on horizontal networks on lower levels by lesson drawing, networking and competition.
5. Create (feedback) mechanisms to monitor the impacts of a policy.
6. National government should lead and take responsibility, and also engage in competition.
7. Use the multi-sectoral approach to integrate economic co-benefits in policies.
8. Focus on technical change and use a technology based economic approach to climate policy essentially, but without excluding non-technical aspects.
9. A broader approach is based on the coalition between sectors, operating on all levels, in promoting both economic and non-economic co-benefits from a broad interest base.

Circular Economy

The fundamental approach to this project is based on the concept of Circular Economy (CE). CE describes the attempt to redefine our approach to resources and change the current resource use paradigm from linear to circular. It seeks to change the "manufacture-use-dispose" system, in which little concern is given to the limitability of raw materials and disposal of the products, into a circular system, where products that have served their original purpose can be turned back into resources and subsequently be used for manufacturing new products. This minimises both the amount of raw materials of the product's life cycle on one hand and waste on the other (Stahel 2016). Adopting CE involves a number of stakeholders and initiatives other than simply recycling waste; it requires re-thinking of the product design and consumption, often introducing completely new ways to extract value from resources that are in the loop for a longer period of time (Bocken et al. 2016). According to Ellen MacArthur Foundation, CE must provide "*long-term resilience, generate business and economic opportunities, and provide environmental and societal benefits*" (EMF n.d.).

Principally, CE can be introduced in all sectors, including energy and agriculture. The anaerobic digestion technology enables reuse of secondary resources, such as food waste, manure, industrial waste or wastewater, for production of energy. A by-product of the process is degassed digestate that can potentially be applied as a fertiliser in agriculture. The process allows to both generate energy and reuse nutrients trapped in these materials that would otherwise be lost or, if not treated properly, could do damage to the environment. Through this possibility to reuse resources and keep nutrients in the loop, anaerobic digestion bears a potential to significantly limit the use of resources and solve the problem with their disposal. In this way, it is an good example of a technology that can help turning the society and economy in a more circular direction. The following chapter will present the concept of CE and explain the role it plays in the project.

CE has been known at least since the 1970s, but already in 1966 Kenneth Boulding lay the grounds to the concept in his essay called "*The Economics of the Coming Spaceship Earth*" (Boulding 1966), where he attempted to raise awareness that neither the planet's input resources or output sinks are unlimited (ibid.). For over 40 years, the attention dedicated to CE has been very limited; in recent years, significant progress in terms of research and popularisation of the concept has been made. The most prominent organisation that deals with promoting CE is Ellen MacArthur Foundation; The Foundation has developed a number of reports and sponsored a significant amount of research. Still, numerous researchers, such as Stahel (2016) have stated that the concept is not very well researched, while some have argued that the current scientific understanding of it is very limited, "*superficial*" and "*unorganised*" (Korhonen et al. 2018:37). Despite this, CE has recently received wide attention on the international political level, e.g. as a part of the EU agenda. Circular initiatives have played a role in a variety of plans across many sectors. The most prominent example is the European Strategy for Plastics that has been largely present in the European media (EC 2018b), but there are several initiatives that bear relevance for this project.

In 2015, European Commission adopted a Circular Economy Package with the aim to facilitate the move to a "*more circular economy*" (EC 2015). The Circular Economy Package presents 54 actions across different sectors and is revolving around a variety of resources (EC 2019b). The report puts a strong emphasis on waste management, but names bioenergy (ibid.: 15), fertilisers (ibid.:8), livestock (ibid.:12) and much more with a large degree of relevance for biogas. It suggests e.g. strengthening the bioenergy market and "*Ensuring coherence and synergies with the circular economy when examining the sustainability of bioenergy under the Energy Union*" (ibid.:15), which could shed some light on the diverse advantages of broad use of anaerobic digestion technology for the policymakers. In 2019, the European Commission released a report on the implementation of the Action Plan which names a number of existing initiatives that bring some of the 54 actions from the CE Package to life (EC 2019a); some of these initiatives can be of importance for the biogas industry. The *Revised Waste Legislative Framework* that entered into force in 2018 defines the new plan for recycling rates and includes rules and obligations on separate collection of waste (ibid.:4). The *Fertilising Products Regulation* introduces standardised rules for organic fertilisers recovered from secondary resources, e.g. through biogas production and creates a single European market for such products, reducing the market barriers for circular products; it also introduces standardised limits for toxic contaminants in these fertilisers, prioritising soil protection and making it easy for the CE-certified fertilisers to be sold on European markets (ibid: 5; EC 2016b; EC 2018b). The regulation will become mandatory to implement in 2022.

There are many more examples for the fact that CE, and bioeconomy in particular, have a high priority on the EU agenda. On the basis of that, we would argue that sustainable expansion of biogas is not only in EU's interests regarding popularisation of CE, but also directly can play an important role in realising the EU goals and plans.

Chapter seven: Analysis

In this chapter, the interviews taken with the experts Frank Hofmann and Bruno Sander are analysed and set together with the scientific literature. The aim of the analysis is to highlight the necessary technical factors that need to be considered when creating a policy for development of the biogas sector. The case of Germany as a country that already does have a large biogas sector will be used throughout the chapter; this will be supplied with examples from Denmark, as one of the interviewees bases a large part of his considerations on his own national context and policies. This data will be used in the later part of the project for creating policy recommendations that would support circular use of resources. The policy recommendation will be presented in the next chapter. As described in the chapter "Analysis strategy" the chapter will be divided in an input side and an output side to explore each of their role in relation to each other and their role in a systems network.

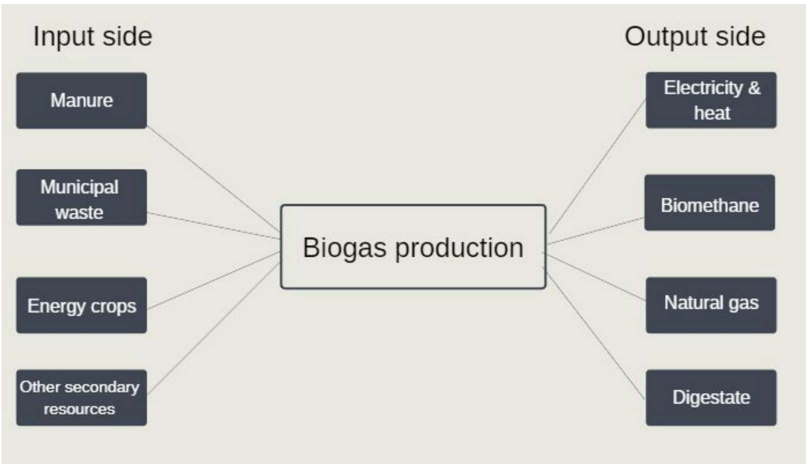


Figure #21: Analysis strategy. Own work.

Input side

Throughout this report, energy crops, manure and municipal organic waste have been considered the main inputs for biogas production. This section discusses the potentials and problems linked to their use as well as other considerations that are relevant for their implementation. The considerations are based on the empirical data gathered through the interviews, as well as scientific literature that discusses these inputs in the context of usage within the system of the biogas production. This section will also present the primary energy potential of each of these resource categories and assess the possibilities for their role in the expansion of the biogas industry; such expansion is context-related, so in order to set these considerations in perspective, the example of Germany will be used to relate the specific inputs to how these fit into the German infrastructure, as presented through the empirical data.

Manure

Manure is an organic matter derived mostly from animal feces. It can take different forms, such as slurry (feces and urine produced by farm animals kept indoors) or farmyard manure, (feces and urine mixed with plant material used as bedding for animals). A third, non-animal type of manure is called green manure and it is made from crop residues collected from fields. Manure is one of the preferred feedstocks for biogas production; since it is a secondary resource, there is a benefit in using it over feedstocks produced specifically for the purpose, such as energy crops. Anaerobic digestion of manure and its subsequent application as a fertiliser is a prime example of a move towards a more circular economy in agriculture; the nutrients are circulated within the system and there is an additional energy yield. As mentioned in chapter three (under *Digestate*), there is also a GHG benefit linked to anaerobic digestion of manure linked to limiting the storage of manure in open silos (Lukehurst et al. 2010).

In terms of the potential as feedstock in Germany, it is relatively large for manure. Livestock farming constitutes a very large portion of German agricultural production and it is estimated by FAO that German livestock production makes up 3% of the world's production (Oehmichen & Thrän 2017). Thrän et al. (2014) estimates that as of 2013 there was 139 megatons of excrements, including liquid and solid manure as well as slurry (Thrän et al. 2014). These figures are likely to have dropped slightly since, as Germany's meat production has dropped, e.g. from 1 143 000 tons of beef in 2014 to 1 129 000 tons in 2017 (Statista n.d.b). The material contains a significant amount of nutrients that can be beneficial for agriculture and is typically used as fertiliser (Oehmichen & Thrän 2017). As mentioned in the section above, the manure has a large potential to be used for biogas production; this is especially relevant in Germany, as the German state has developed a regulation (Verordnung über die Anwendung von Düngelmitteln) that prevents livestock producers from storing the manure in open silos, where large amounts of methane from manure are released into the atmosphere (Oehmichen & Thrän 2017), estimated to be as high as 1% of the overall German greenhouse gas emissions (Haenel et al. 2014). Despite these high numbers, it is important to emphasise that biogas yield from manure is significantly lower than from energy crops or biowaste. This means that large amounts of manure may still not be sufficient to fuel the whole biogas sector, but the GHG emission mitigation potential still makes treating of manure beneficial.

Scarlat et al. (2018b) have developed a map of spatial distribution of livestock and poultry that could potentially be of use for biogas production in Europe. According to this study, there is 175.5 million tons of manure produced in Germany, 132.5 of which is estimated to be collectible, roughly corresponding to 2907 million m3 theoretical and 2213 million m3 realistic biogas potential (Scarlat et al. 2018b). The geographical distribution of the manure, illustrated on the map below, is, however, largely centered around the northeastern German state of Lower Saxony (Niedersachsen) (ibid.). The authors emphasise at the same time, that there are several local factors that can be of large importance, so the actual economical feasibility of the potential plants is not a part of their study, and locations should be assessed on an individual basis (ibid.). According to another study by Scholwin et al. (2014), the energy potential of manure as a biogas input is 10 TWh of energy per annum (Scholwin et al. 2014).

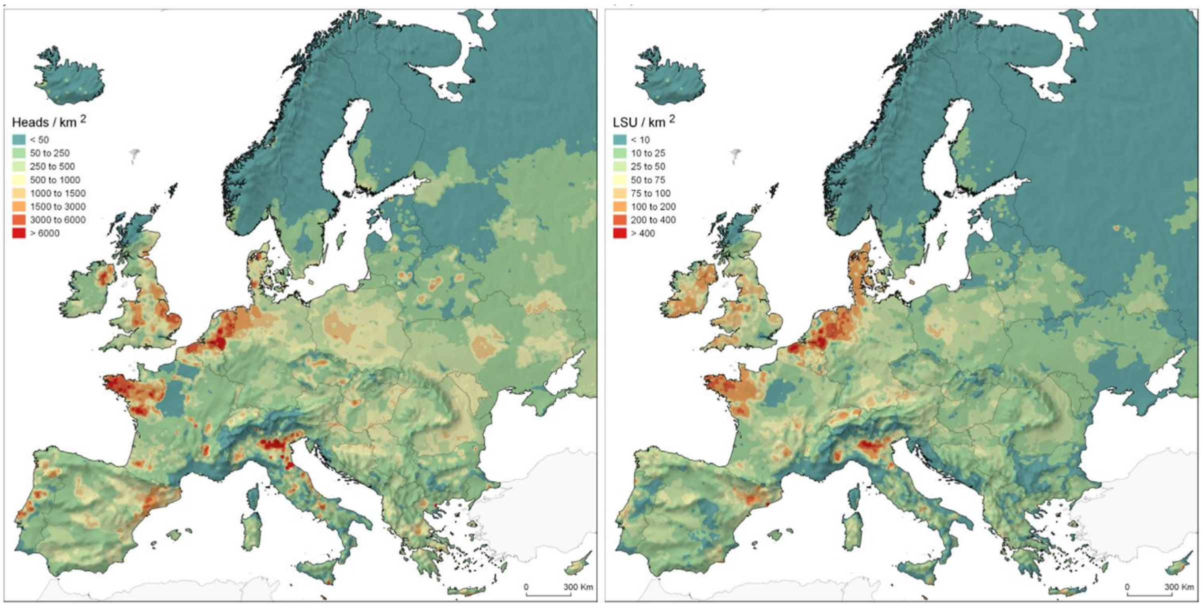


Figure #22: Spatial distribution of a) livestock and poultry and b) livestock unit (LSU) in Europe (Scarlat et al. 2018b).

In the context of the aim of the project, the subjects of the interviews have been asked to identify the potential factors that need a thorough consideration in the context of creating a policy that would reduce the demand for energy crops. First and potentially most significant issue is the low methane yield of manure. As Frank Hofmann explains it:

"*The feedstock that can be used for biogas has very different kind of biogas yield, the amount of biogas per amount of fresh mass. Manure can create 20-25m3 biogas per ton, maize silage about 200-240. It is very logical, because the cow is eating maize silage using much energy to grow, move and digest and what comes out of the cow is already digested so there is not so much energy in manure so the yield is lower.*" - Frank, App. 3:2

The low methane content in manure means that much less biogas can be produced from the same amount of input material. This can be relevant for the biogas producers that receive the FITs; a biogas plant has a limited physical capacity, so the amount of energy that they can produce is dependent on the input; if the input is manure, then it is only possible to produce much less energy from it at once. This issue is connected to the size of the plants. As Frank explains:

"*The problem is, let's take an example of a medium-sized biogas plants, 200 kW,; if it should be based on pure manure then there would be a need of 1700 livestock unit and that's a huge farm. A typical farm* [has] *some hundreds, sometimes just a few livestock units. 1000 is a really big farm and you see that if the pure manure should be used, then the results are mainly smaller biogas plants and very few larger biogas plants that could survive.*" - Frank, App. 3:2

The consequence of expansion of manure biogas production is that the energy capacity of single plants would be much smaller than in the current setup with energy crops. For that reason, it is emphasised that energy crops cannot be fully eliminated. Having more smaller plants is not necessarily an issue, but it is stressed in the interview that large plants are economically more feasible than small plants. "*One important point is that the bigger the size of the biogas plant, the lower the cost of energy production. Smaller biogas plants have very high cost* [per] *kilowatt hour*" (Frank, App. 3:2). Also, Frank points out that if the expansion for smaller plants and reduction of the larger plants would happen, biogas would not be able to play a significant role in the German energy mix: "*if we are to rely only on manure then the biogas plants will be smaller and the transition for industrialised country is just not enough*" (Frank, App. 3:3).

As a solution to this issue, it is recommended to mix manure with small amounts of energy crops: "*if you add energy crops, let's say 80% manure and 20% crops, you would only need about 700 cows*" (Frank, App. 3:3). Energy crops, having a much larger biogas yield, could exacerbate the amount of produced biogas, even if added in small portions. The table below shows that.

		% of cow manure used			Cow dung and straw
El. Installed capacity		100%	90%	80%	
50 kW_e	LSU	429	261	174	193
100 kW_e	LSU	859	521	347	387
150 kW_e	LSU	1288	782	521	580
200 kW_e	LSU	1717	1042	695	773
250 kW_e	LSU	2147	1303	868	967
300 kW_e	LSU	2576	1563	1042	1160
350 kW_e	LSU	3005	1824	1216	1353
400 kW_e	LSU	3435	2084	1389	1547
450 kW_e	LSU	3864	2345	1563	1740
500 kW_e	LSU	4293	2605	1737	1933

Figure #23. The amount of livestock units needed to fulfill the different capacities, when mixed with different amounts of energy crops. Source: Frank Hofmann.

This solution is in conflict with the aim to eliminate energy crops, but might be the only economically feasible option to reduce the amount of them. Anaerobic digestion of manure can still significantly reduce GHG emissions, and this should always be prioritised.

Because of such input rotation, an issue of biogas plant flexibility is important to mention here. Bruno Sander mentions this issue when asked, whether it would be technically problematic to switch the input from energy crops to manure. His answer indicates that it would not be problematic for German biogas plants to use liquid input, but mentions Danish digesters that are not built to use inputs that are non-liquid:

"*Det har jeg simpelthen svært ved at se hvorfor de ikke skulle kunne* (...). *De kan pumpe væske ind. Og det kan man med gylle. Det er sådan set os der har den anden og det er os der har en udfordring, fordi vores biogasanlæg er designet til at modtage gylle og flydende industriaffald*" (Bruno, App. 2:9).

For this reason, when designing digesters, it is necessary to take the possibility to change inputs into considerations.

The final factor that has been discussed in relation to manure is the vendor involvement. The rules for who pays for the input material are unclear. As Frank explains:

"*usually someone has to pay if he has waste to be treated, either incinerated or used in biogas plants* (...) *but this is changing. The people who are producing waste see that it has some value and there is a change of paradigm* (...) *now they are selling the energy that is inside waste.*" - Frank, App. 3:6

Both interview subjects have been confronted with the idea of remunerating vendors; to Bruno, the possibility to exchange manure with digested manure is beneficial enough by itself, as the crops can better benefit from the fertilisation from digested manure (Bruno, App. 2:10). Frank does neither express any opinion on the topic on behalf of GBA nor his own, but recognises that a part of the reason for the previous German biogas legislation worked so well, was that the "*trader of energy crops that made good profit, so for them it was a business*" (Frank, App. 3:6) and says that all parts would benefit from uniform rules (ibid.).

Municipal & industrial waste

Municipal waste is in this report covering the organic fraction of the overall collected and sorted waste. According to the German Environment Ministry data, most of the municipal biowaste, along with biodegradable garden and park waste, market waste and other biowaste in Germany is already treated in either composing and digestion plants or biogas plants (BMU 2018). In 2015, 13,85 million tonnes were treated this way and the tendency seems to be rising (ibid.). The data, however, does not specify the ratio between composting and anaerobic digestion; in this context, it could be argued that anaerobic digestion is a better use for municipal biowaste than composting, as, along with recovering nutrients, it also enables energy production. According to Scholwin et al. (2014), the potential of municipal waste as a biogas input in Germany is between 1,5 and 3,7 TWh per year (Scholwin et al. 2014).

The sorting and collecting are major preconditions for being able to use this fraction. This issue has been addressed by EU which sees it as an unused potential (EC 2016). It is mentioned that the dry matter of municipal organic waste is higher than manure, a rate that is connected to the amount of biogas yield, which is a valid incentive to produce biogas from this fraction (Bruno, App. 2:11). It is a part of the EU CE Package to increase the recycling rate and make sorting and collecting obligatory by 2023.

In Germany, the reason for the exclusive use of energy crops is also that the policies to promote biogas production (see chapter five on Germany) were exclusively connected to the agricultural sector and not waste sector. For this reason, the municipal waste was not even considered an input (Bruno, App. 2:8), which means that very little amounts of organic municipal waste overall was recycled. This is an example of the sectoral division that should be addressed in further development. Frank also mentions how the incentive for recycling organic waste relies on being more beneficial than incineration of the waste:

"What would help biogas would be the municipalities' interest in doing something to invest into biogas plants instead of incineration(...) *It would be good if local municipalities or companies which are trading waste would transfer this system into biogas. There is a need for some real regulation to help with it."* - Frank, App. 3:8

The production from energy crops was also stable and created a flat energy output (Bruno, App. 2:8), where now other systematic functions like acting as a buffer in a fluctuating system is in greater demand, on top of rising demand for greater shares of sorting, collecting and recycling by the EU.

As for the industrial waste, it is mentioned in the interviews that it is already used as fodder for livestock. Frank explains:

"*If rapeseeds are growing for biofuel, the residue is usually used for the animals. Sugar beets use residues also for animals. Of course, these kind of things could be used for biogas production, but they are already in use in Germany. And we do not want to be in competition with food production.*" - Frank, App. 3:4

The non-competition with the food industry is principally one of the reasons for wanting to depart from using energy crops, as the space used for growing these could be used in food production agriculture; the German case is an example of this conflict, but in other countries, or with materials that are not suitable for use as fodder, making incentives for use of the organic waste products from industries in biogas production should be considered.

As earlier mentioned the factor of the practical circumstances concerning the texture on the input, especially the consideration that biogas plants have to be designed for both types of textures, meaning that the receiving area should be made suitable for both liquid and solid materials (Bruno, App. 2:9) also concerns the use of municipal waste as input.

Other inputs

Anaerobic digestion process is also widely used for treating wastewater in Germany (KA 2014), but due to the risk of soil contamination with heavy metals and overabundance of elements such as cadmium and zinc, the German government together with the Federal States (Länder) have decided that use of sludge in agriculture should be minimised (BMU 2018). Perhaps for that reason, the interview subjects did not elaborate on the issue.

"*We don't have it, and this is driven by the German law. We have a separate system for wastewater, as it is not legally allowed to use digestate from wastewater on agricultural fields*" - Frank, App. 3:5

Digestate from wastewater, in accordance with the German law, should be dried and incinerated (Frank, App. 3:5), and wastewater digestion system is seen as a separate system by the GBA (ibid.). In Denmark, the digestate from a wastewater plant is allowed to use but only on non-organic agricultural land (Bruno, App. 2:11). The reason for that is that the digestate might consist of too many unknown substances such as potentially dangerous chemicals or heavy metals (Mijøstyrelsen n.d.). To utilise this resource, an assessment of the tolerable levels has to be made to determine the possibilities of bringing the digestate through a thorough cleaning process or a regular testing.

Energy crops

As mentioned before, energy crops have a large and consistent biogas yield and, in the German case, it would be impossible to come even close to reaching the current levels biogas production without including energy crops. Complete removal of energy crops is therefore not encouraged. However, since the GHG-emission reduction effect is much lower for energy crops than for secondary inputs, and because growing energy crops requires a lot of space that otherwise could be used for growing food crops, it is recommended that the use of energy crops is minimised. The solution that Germany is implementing at the moment is to keep the current amount of energy crops, but not reduce it:

"*We are now at the status quo of 1,3 million hectares used for biogas feedstocks and that will stay. We will not enhance it very much*" - Frank, App. 3:3

All attempts at exchanging energy crops with secondary resources will result in lower biogas yield. In countries where biogas is supposed to play an incremental role in the energy system, this is not an optimal option. In such cases, a change of energy priorities would be necessary. Countries such as Denmark, where use of energy crops for biogas production is not widespread, it is the large agriculture sector and production of livestock that makes production of significant amounts of gas possible. This, however, is not the most sustainable choice, as animal livestocks have a large environmental impact.

Output side

The following section focuses on the output side of biogas production. Output here should be understood both as the main product of anaerobic digestion - biogas, and the possibilities of its use as gas for electricity generation in CHP (Combined Heat and Power) or as biomethane in the transport sector, but also the biogas by-product - digestate. Factors that could be relevant to consider when creating a policy for a sustainable development of the biogas industry will be highlighted here. Just like the previous section, this one draws from the empirical data from the interviews with Frank Hofmann and Bruno Sander as well as scientific literature on the subject, especially EU report *Optimal use of biogas from waste streams* (EC 2016a).

Electricity & heat

“*Much more energy is used for heat: cooking, hot water for the shower - much more energy is used for that than electricity. That will be the future. Biogas can be used in homes to heat them*” - Frank, App. 3:6

While electricity is the most widespread possibility for use of biogas, incineration of biogas often happens in CHP plants; according to EBA only 25% of the heat is utilised (EC 2016). This is due to the fact that biogas production is often not in the proximity of the users (ibid.). Therefore, it is recommended that incentives for usage of rest-heat from biogas use are provided. This could improve overall energy efficiency and give biogas a larger role in terms of energy consumption. This could be done by choosing the CHP which is in a closer proximity to the demand for heat, as it is difficult to transport heating over larger distances. The case example, Germany, does already have policies that incentivise use of heat from biogas.

Biomethane

One possible application of biogas that has a large potential is the use as biomethane. The process of upgrading biogas to biomethane is described in chapter three. Biomethane can be used in transport sector or injected into the natural gas grid. Biomethane in the EU is currently covered by the market rules for natural gas, which is understandable, considering it has the exact same chemical features and also because the share of biomethane in the gas grid is relatively limited (EC 2016a). It might, however, be beneficial to consider creating special rules for biomethane from biogas to emphasise its origin, as its usage bears a potential for reduction of GHG emissions (ibid.).

The interviewees present use of biogas in the transport sector as a large potential. Frank explains that “*we cannot electrify everything, such as trucks. To improve the situation for transportation might be the future of biogas - take some waste, upgrade it to biomethane and compress it.*” (Frank, App. 3:6). He brings the example of biomethane usage in Sweden to show the difference in philosophy of the two countries, but also to present a motivation to use biogas in transport: "*if you compare Sweden with Germany, the Swedish motivation is driven by the lack of alternatives in transportation. In Germany the discussion was different: we made LCA and we figured out the best GHG effect*." (Frank, App. 3:6).

A suggested action that could help biogas become a part of the transport sector is making a more significant quota for renewables' share in the transport sector:

"*For this we have a quota but the quota is currently very low. 6% less greenhouse gas emissions compared to the baseload. But there should be much more incentive for RE to be use in transport and on opportunity is quota for renewable energy instead of fossil fuels*" - Frank, App. 3:6

For this to succeed, there is a need for infrastructural developments. If transport is to be based on natural gas, there must be vehicles that can use LNG (liquified natural gas) or CNG (compressed natural gas) as fuels, and there is a need for filling stations that can handle fuels in this form. Use of biomethane in German transport is limited, but Frank brings one particular example of it: the self-sufficient urban biogas system, where garbage trucks are using biomethane to collect waste and drive it to the biogas plant on the outskirts of Berlin. This is a prime example of circular thinking:

"*in Berlin, we are separating biowaste, we have a green bin, and that separated waste is going to the biogas plant and upgraded to the biomethane quality, and the trucks of the waste collecting company are operated with CNG, so using the energy from biogas to collect the waste, which is a great recycling loop.*" - Frank, App. 3:4

He points out, however, that "*it does not make sense economically*", as there is a need for large amounts of input for the plant to be able to sustain itself (Frank, App. 3:4). For this reason, policies encouraging such closed loops of resource use could be of help for the sector to become more circular.

Digestate

Digestate is the byproduct of anaerobic digestion that can have significant environmental benefits when used as a fertiliser, such as preventing nitrate leach and the potential of nutrient recycling. To promote recycling of waste and digestate use, economical incentives has to follow. Currently, there are no economical incentives for farmers to digest their manure in biogas plants. In Denmark, which is an example brought up by Bruno, the profit has been confined to the owners of the biogas plant or by owning parts of it:

"Men det [at tjene penge] *kan man jo gøre hvis man ejer biogasanlægget. Enten et gårdanlæg man ejer selv, eller hvis det er et andelsselskab som ejer biogasanlægget, hvor det er landmændene i fællesskab der ejer det, eller som det er med de nyeste der bliver bygget i dag, hvor det typisk er et energiselskab der ejer mindst 50% og så kan landmændene eje op til 50%, men der får de selvfølgelig også en andel af det overskud der nu måtte være på driften."* - Bruno, App. 2:10

However, the Danish system functions through a set of other factors that motivate the farmers to use anaerobic digestion: it helps fulfill the water regulation requirements and reduces odour. As described in chapter three: biogas technology, the digestate from either manure or municipal organic waste has an environmental advantage, improving plant availability which results in lower rates of nitrate leaching, which is the reason for being able to live up to water regulations. This "Danish model", according to Bruno, emerged from the problematic situation of too high leachate rates as a cause of unregulated use of manure as fertiliser, and that biogas plants treated the manure into a better product preventing a certain amount of leach. For this the distribution and a fertilising system evolves in a certain extent around a biogas plant. Since the the physical aspects, apart from the stored gas, is anchored in the local community. This made Bruno see the biogas plant as a "centre of logistics" and that the profit out of the energy is financing the operation (Bruno, App. 2:8). *"Så man kan sige at gevinsten for landmændene har været at man fik den der logistik platform til at få omfordelt noget, og så fik man noget tilbage der havde en bedre gødningsværdi"* (Bruno, App. 2:9). This could potentially be a relevant potential for German farmers that struggle with high rates of nitrate leaching.

Another point is the differentiation of requirements regarding the use of digestate in agriculture on international level (EC 2016a). Currently, the use of digestate is not regulated, as any digestate including a portion of manure is treated as 100% manure and as such, is a subject to strict limits. EC 2016a suggests that the requirements should be based on the nitrogen content and amount of manure in the digestate.

Additional considerations

Another factor mentioned in the interviews for benefitting the popularisation of biogas from secondary inputs is bureaucracy. Bruno mentions that in Denmark, obtaining all formal approvals to start building a biogas plant can take six to eight years: "*det tager 6-7-8 år at få bygget et biogasanlæg, med alle godkendelser*" (Bruno, App. 2:5) which makes the investments and emergence of new biogas plants sensitive to the changes in policies. Reduction of the bureaucratic burden on specific biogas projects, after the country demand, could have an influence on the outcome.

Chapter conclusion

To sum up, the choice of input category is dependent on its intended function. Energy crops are grown because of their large biogas yield potential (200-240 m^3/t), whereas manure has a low energy yield, as a cow already acts as the digester, which leaves the yield at 20-25 m^3/t. The yield of municipal waste is somewhere between those two (120-140 m^3/t), in some cases exceeding the yield of energy crops (600 m^3/t) depending on the contents of the waste. When it comes to GHG reduction, the order is inverted, making manure stand for the highest reduction, energy crops the smallest reduction and municipal waste is situated in the middle (Frank, App. 3:2). When designing the biogas system, considerations of which advantage should be prioritised is therefore necessary. Many other factors are also important for determining which input should be favoured, which are mainly practical and financial concerns.

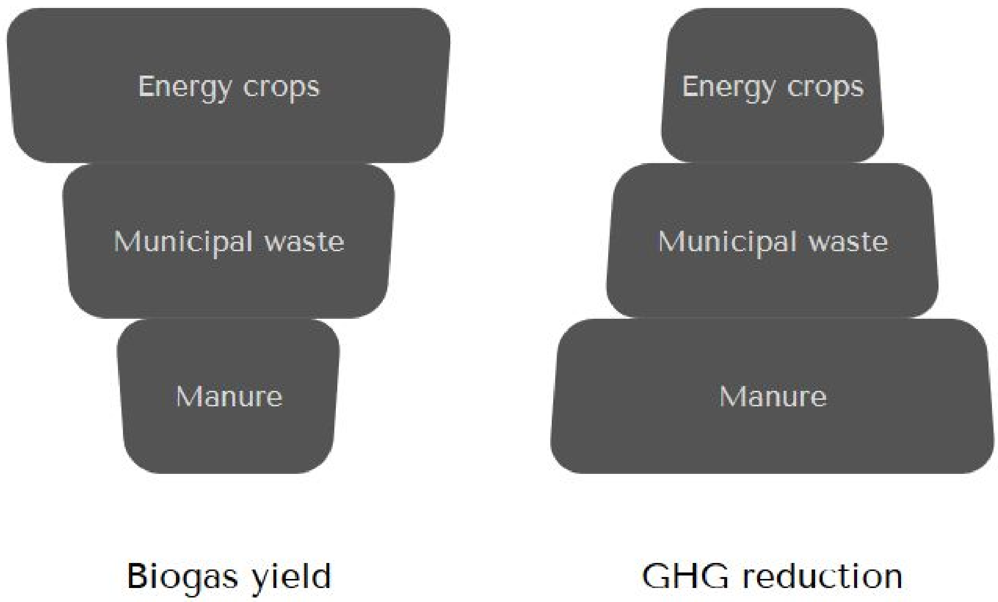


Figure #24: Methane yield and GHG reduction potential for biogas from different input material. The broader the field, the larger the potential. Own work.

Other input-related issues include involving the input vendors in the remuneration that has potentially favourable effects, the need to build flexible digesters that can receive the input in many forms, creating incentives for separation of biowaste, and reducing the bureaucracy burden on the input side that could be favourable for development of biogas from secondary inputs. As for the output, it would be beneficial for sustainable biogas expansion to create incentives for using heat from CHP from biogas, differentiate biomethane from biogas from methane on a policy level, introduce quote for renewable energy in the transport sector, create infrastructure in the transport sector, highlight the nitrate-related benefits of using digestate and differentiate digestate from manure in the rules for fertilisers.

Chapter eight: Discussion

Based on the previous chapters, this chapter will present specific policy recommendation for the EU in order for the sustainable expansion of biogas to take place. Policy recommendations are divided in 5 categories. The discussion will apply to the specific position of the EU in a global context where, according to the systematic framework of MLCG. The EU is at the level of the world regions where potential horizontal action at lower levels is to be encouraged and stimulated through policies.

1. Prioritise secondary resources as inputs

There is a large potential within the EU to create frameworks for expansion of secondary resources use as inputs for biogas production, but this needs to be prioritised. Firstly, ambitious targets for bio waste separation are a prerequisite. The EU directive 2018/851 amending Directive 2008/98/EC on waste specifies that "*Member States shall ensure that, by 31 December 2023* (...), *bio-waste is either separated and recycled at source, or is collected separately and is not mixed with other types of waste*". (EP 2018), but while the overall target for all municipal waste recycling is set to 65% by 2035 and there are recycling target rates specified for packaging, plastic, glass, cardboard etc., there is currently no concrete target for biowaste.

Secondly, the biogas sector could benefit from the possibility to receive a variety of inputs. Plants built specifically for digestion of solid material can usually be used for liquid material, but not the other way round; the possibility to do so would be beneficial, should e.g. the ratios of manure and waste change. For this reason, our recommendation is to include some degree of standardisation of the digesters; doing this on an EU-level would not be easy, as there is a risk of not being compliant with the EU competition principle, and as it can be seen with any other standardisation efforts.

2. Involve more actors in the system financially

An inclusion of all stakeholders involved in biogas production is a prerequisite for building a healthy industry. Stakeholders' interests must be taken into consideration and one of this project's recommendation is to incentivise participation in biogas projects for all actors; these actors include but are not limited to: vendors of feedstock, such as farmers and municipalities, regional authorities as well as citizens. As discussed widely throughout the project, the most important factor contributing to expansion of any kind of biogas system on a larger scale are the financial incentives; the example of Germany shows that feed-in tariffs can have a significant influence on the shape of the whole sector; for this reason, an expansion of the feed-in tariffs so it includes other actors is a potential contributor. Due to the large degree of context-dependence, among other reasons, the design and control of the feed-in tariffs are competencies of the Member States, rather than the EU. While the EU does not officially have a role in the process, it does address the issue in the official guidance for renewables, which, however, does not include any recommendations for specific policies, but serves as an assistance for creating the policy framework (EC 2013). Furthermore, the EU has the possibility to incentivise anaerobic digestion of manure in other ways, e.g. as a part of the agricultural policy. In the same way the EU financial support for farmers under Common Agricultural Policy is given under the condition of taking certain environmental measures, anaerobic digestion could also become a requirement. Municipalities should also be incentivised to use anaerobic digestion rather than incineration for waste treatment; the prerequisite for this is that there are policies encouraging waste separation. In Berlin, for example, the waste collection infrastructure is closely linked to biogas, as e.g. the waste collecting trucks use biomethane as fuel. As highlighted in the interview, however, this is not necessarily economically feasible (Frank, App. 3:4), so such measures should be encouraged, e.g. by creating targets and strategies for the inclusion of renewables in various sectors, such as municipal waste collection. One burning issue when it comes to expansion of biogas is the citizens' resistance to creation of new projects in their vicinity. Including citizens is essential and because of issues such as odour, digesters should not be built too close proximity to the residential areas; on a larger perspective, however, the citizens should be incentivised to welcome biogas plants in their local areas. This could be done by creating benefits for the communities that host biogas production.

3. Promote the transport sector

In the revised Renewable Energy Directive (RED) from 2018 (EU 2018) it is described how biogas and renewable energy in the transport sector can contribute to a low-carbon economy and *"energy diversification in the transport sector while promoting innovation, growth and jobs in the Union economy and reducing reliance on energy imports."* (EU 2018). A minimum national share of use of biofuels is intended by the EU. However, incentives to invest in infrastructure like gas filling stations and vehicles running LNG or CNG are needed. The EU should create incentives to expand the share of biogas upgraded to transport fuel, as this is a potential future market for alternative to both fossil fuel which is emitting large amounts of CO_2, and transport running on electricity which demands a different infrastructure of network such as electrical wires. A policy should address incentives towards the function of flexibility and biogas being a buffer function next to wind and solar in terms of electricity production. These can in a MLCG perspective include a cooperation between electricity producing sectors and competition in the transport sector and thereby stimulate horizontal activity on the concerning level. There should also be taken into account how the production of fuel can remain stable in situations of demand in electricity.

The 2018 RED, article 91 also states the following: "*feedstock which has low indirect land-use change impacts when used for biofuels, should be promoted for its contribution to the decarbonisation of the economy. Feedstock for advanced biofuels and biogas for transport, for which technology is more innovative and less mature and therefore needs a higher level of support, should, in particular, be included in an annex to this Directive*". We recommend that a suggestion to an even higher prioritization of waste streams over feedstocks grown specifically for the purpose, if possible, be added to this point. There is, however, an uncertainty to which degree low indirect land-use change is determined, and LCA of the feedstock might also be of importance.

4. Promote digestate use

The digestate is one of the main preconditions for biogas production being a system of a circular economy. By promoting and creating incentives for the treating of manure and the biogas plant as a waste management technology, the environmental benefits are increased through that policy. Because of this, the biogas sector and the agricultural sector are closely aligned. Policies in both sectors should therefore meet and promote interests of both actors. However, the distribution and content of the digestate is rather complex. The digestate is already promoted as a beneficial and nutrient rich fertiliser by the EU, as long as it is derived from clean feedstocks (EC 2016a). The harmonisation of regulating the feedstocks as inputs across EU borders are therefore requested and can promote co-digestion and an international trade market for the digestate (EC 2016a). Context dependent factors are also included, since different feedstocks are used in different countries and as distribution needs to consider water- and nitrate regulation depending on the area. The "*Fertilising Product Regulation*", recently proposed by the European Commission could be a groundbreaking piece of legislation for the purpose of digestate promotion; in the current proposal, however, digestate is only named briefly and there is no particular focus on digestate from biogas production (EC 2016b).

5. Create common sustainability standard

Last but not least, one absolutely crucial measure that should be taken for biogas expansion to succeed is creating a standard for sustainability criteria for biogas and biomethane in EU countries. Sustainability criteria can create flexibility in feedstock use and ensure the sustainability of the overall end product (EC 2016a). As sustainability criteria allows to promote the use of co-digestion, higher biogas yields can be obtained and create financial benefits and incentives to increase GHG savings (ibid.). This could also enable the possibility of cross-border trade of feedstock and digestate, enable public support and validate the benefits from anaerobic digestion and biogas production (EC 2016a). A special directive for this purpose should be endorsed.

As according to the PCM, these recommendations serves as the relevant factors that are included in the phase of identification. With that said, however, it is acknowledged that many other systematic factors and a more resourceful research area across the sectors should be performed before continuing to the following phase, if a similar project were to be realized.

Conclusion

This project has examined the possibilities for the EU to create favourable conditions for a sustainable biogas expansion. Multiple environmental benefits of biogas have been highlighted: biogas can serve as a stable backup for renewables and be used in the transport sector; it can replace fossil fuels and therewith contribute to mitigating GHG emissions; it allows recycling of soil nutrients and is a safe way of waste treatment, contributing to creating a circular economy. Challenges of biogas expansion, such as potential methane emissions and social resistance can be avoided when addressed accordingly. The project determined that the main driver of the unprecedented biogas development between 2009 and 2014 in Germany was the large degree of support through feed-in tariff policies; however, the vast majority of German biogas is produced from energy crops, rather than secondary resources. Based on this, interviews with Frank Hofmann from the German Biogas Association and Bruno Sander from the Danish Biogas Association have been made to determine what issues should be considered in order to develop a biogas industry based on secondary inputs. A number of issues were highlighted in the interviews: the issue of low methane yield of manure-based biogas, making limited use of energy crops in the feedstock mix justifiable; not including input vendors in remuneration; limited incentives for separation of biowaste; lack of incentives for using rest heat from biogas; lacking differentiation of biomethane from natural gas in the policies; missing infrastructure and low RE quota in transport sector; treating digestate in the same way as untreated manure in the policies. In order to create a more favourable conditions for the development of biogas from sustainable inputs, the EU, being on “the level of world regions” in the MLCG framework, has the necessary competencies to take following measures: set targets for bio-waste separation; involve multiple stakeholders in the international guidance for the FIT scheme or further incentivise anaerobic digestion through its agricultural policies; validate the environmental benefits of digestate by harmonising rules for digestate content across countries; create a common sustainability standard for biogas, so it can be traded across state borders. This, according to the MLCG framework, should stimulate action from the Member States.

Further research

This report has been presenting new policy recommendations on behalf of the EU. For further research, policies created at a lower level and specifically the national level would be of relevance to achieve a more concrete and action oriented perspective towards the expansion of the biogas sector. Research on the potential collaboration between the sectors and how the sharing of knowledge can be able two travel and used constructively across the levels can be relevant within the system of MLCG. On top of this, a follow up of the current National Renewable Energy Action Plans and the development of the future national strategies, goal setting and potential actors can be further analysed.

Another issue that is relevant for biogas production is the livestock farming. Meat consumption is an important source of GHG emissions, both globally (Aan Den Toorn et al. 2017) and in Germany (Xue et al. 2019). While anaerobic digestion of manure is an effective way to reduce CO_2 emissions connected to livestock, reducing consumption and therewith production of livestock would have a much more significant effect (Xue et al. 2019). Opting out of animal products is becoming more and more widespread in Germany where vegan meat substitutes are widely available in stores (Gerke & Janssen 2017). Limiting the production of livestock would be synonymous with limiting the secondary feedstock supply for biogas production. In such case, the role of anaerobic digesters as a means to sanitise manure would be significantly reduced. Removing livestock would, however, remove an additional link in the resource chain and resources could potentially be used in a more sustainable manner if used directly in digesters, but the issue of maizification would potentially return. Although it is not likely that meat production would become absolutely in abolished in the near future, the scenarios for potential consequences of such development for the biogas sector should be researched.

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