Dimensions and characteristics of biogas policies – Modelling the European policy landscape

M. Gustafsson *, S. Anderberg

Environmental Technology and Management, Department of Management and Engineering, Linköping University, SE-581 83, Linköping, Sweden

**Article Info**

**Keywords:**
- Biogas
- Biomethane
- Renewable natural gas
- Policy
- Regulation
- Institutional conditions
- Policy model

**Abstract**

Biogas solutions typically span across several sectors, such as waste handling, energy and transport. While this can be an advantage in comparison to other alternatives, it also creates an intricate policy structure that is challenging to overview, making it difficult to evaluate consequences of different policy changes that might not be directly related to biogas. This article presents an attempt to describe the institutional conditions for biogas solutions in the EU by defining the dimensions and characteristics of policies and policy instruments influencing biogas. A five-dimensional model of biogas policies is proposed: type of policy; administrative area; administrative level; targeted part of the value chain; and continuity and change over time. This reflects the complexity of the conditions for biogas solutions and constitutes a platform for describing discussing and developing biogas policies. From the proposed model, it becomes clear that biogas policy is a very dispersed and incoherent policy area. Thus, there is an apparent risk that the responsibility for biogas policy is diffuse and has no obvious owner among the involved actors, making the framework of biogas policies patchy and ineffective. This model can contribute to an improved overview of biogas policies, and can be used as a tool for comparing the policy landscapes in different countries.

**1. Introduction**

Biogas production and use have increased rapidly in many countries over the last 20 years, augmenting its importance as a renewable energy source [1]. The biogas production in EU-28 doubled from 93 to 187 TWh between 2008 and 2016 [2,3]. Kampman et al. [4] estimated another doubling to be possible until 2030, and even larger leaps could be possible in individual member states. In Sweden, for example, it has been estimated that the biogas production has the potential to increase by up to a factor 5 from 2013 until 2030 only through anaerobic digestion, and that the total capacity including thermal gasification could be twice as high [5]. However, the actual development of biogas production, both in Sweden and on EU level, has shown tendencies of stagnation in recent years [2]. Realizing the estimated potentials will require the combined efforts of many different actors, not least policy makers, who need to work for strengthening the drivers and removing the barriers for increased production and use of biogas. Many previous studies have acknowledged that policy coherence [6,7], stability and continuity [4,8,9] are central factors for policies to be effective in areas that require large investments over a long time period. This applies to biogas as well as other forms of renewable energy production; a survey among farmers in Czech Republic showed that “frequent changes in legislation” and “complicated and unclear legislation” were the main barriers against renewable energy production in agriculture [10]. Torrijos [11] argued that recent changes in the support schemes for biogas have actually slowed down the development of biogas production and use in Germany, France and Italy. Lönnqvist et al. [12] found that actors in a Swedish region perceived the national policy instruments for biogas unpredictable and that this is probably the main barrier for an increased use of biogas in transports.

Stemming from concerns over climate change, unemployment and energy import dependence, there has been a strategic policy development in many countries to promote biofuels in recent decades [13,14]. This work has been a key driver for increasing the number of biogas initiatives, which were previously mainly focused on waste management [1], but are nowadays often mentioned in the context of renewable electricity and heat (see e.g. Ref. [15,16]), renewable vehicle fuels (see e.g. Ref. [17,18]) and sustainable agriculture (see e.g. Ref. [19,20]). Some countries, like Germany and Italy, have developed extensive systems for producing renewable energy from energy crops via biogas.

* Corresponding author.
E-mail address: marcus.gustafsson@liu.se (M. Gustafsson).

https://doi.org/10.1016/j.rser.2020.110200
Received 14 February 2020; Received in revised form 14 July 2020; Accepted 1 August 2020
Available online 14 August 2020
1364-0321/© 2020 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).
production [21]. Systems for production and use of biogas, biomethane and digestate—often denoted biogas solutions (see e.g. Ref. [22–25])—are renowned for their versatility and their potential to address many societal challenges, including renewable energy production, waste management and nutrient recycling [26]. Moreover, it has been found that biogas solutions can contribute to many of the UN sustainable development goals (see e.g. Ref. [26–28]). This can of course be regarded as an advantage, but on the other hand the many functions and externalities often make biogas solutions complex to evaluate. The policies influencing biogas solutions are also to be found in numerous policy areas, which results in a very complex “policy landscape” that can be challenging to overview and coordinate, thus impeding the potential growth of biogas solutions. Several efforts have been made to describe this biogas policy landscape in European countries, including reports within the projects Biogas Action [29], BIOSURF [30], Record Biomap [31], SYSTEMIC [6] and GreenGasGrids [32]. Although the images conveyed in these reports differ, many of them emphasize the width and the complexity of policies influencing biogas. While investigations such as the above-mentioned project reports contribute with bits and pieces that can geted systems to have the intended effects on the environment. This problem has been noted in several recent studies, including [34–36]. Policies are often evaluated individually rather than as part of a policy landscape, i.e. as integrated and interacting with a broader mix of policies. For example, Deremince et al. [29] made an attempt to explain the development of biogas production in European countries by coupling it to changes in the main economic support schemes, not taking into account other policy changes that occurred during the same time. By doing like this, there is a risk that important synergy effects are missed and that the policy in focus is not the most influential one in that context, which was actually the case in connection with several countries in this study.

This article presents a model for describing the different dimensions of policies influencing biogas solutions in the EU, and how they can be categorized, in a generic way. To exemplify the concept, this model is then applied to a range of biogas policies identified in the literature. While most available reviews aim to describe the policy situation and the implementation of policy instruments in different countries, this article focuses on the general fundamental dimensions and characteristics of biogas policies: where, how and when they affect biogas solutions. The analysis is based on a survey of policies influencing the production and use of biogas, with a focus on European countries.

2. Methods

In order to describe the dimensions and characteristics of biogas policies, a literature review was carried out, focusing on European biogas policies and other related policy literature (Fig. 1). The data and observations from this review were supplemented by interviews with representatives for national biogas associations. The findings were then used to define a model of the institutional conditions of biogas solutions with regards to where they can be found and in what way they affect biogas solutions. Finally, this model was applied to policies relevant for biogas solutions that were found in the literature review.

This study was carried out in the context of the Swedish Biogas Research Center—a national competence center for research on biogas solutions—and more specifically a research project on national (Swedish) and international (EU, other countries) biogas policy. This project includes a comparative study on policies in Sweden and other countries [37]. The literature review and interviews described below were used to provide input to that study as well as to the present study.

2.1. Literature review and interviews

The review draws upon on biogas policy overviews from 2010 to 2019 describing the institutional conditions for biogas solutions in European countries, but it also included other, more generic, literature on bioenergy policy as well as policy documents (e.g. EU directives). A literature inventory was performed, using both Scopus and Google, to cover scientific publications as well as technical reports and policy documents. Terms used for browsing to identify relevant literature were “biogas + policy”, “bioenergy + policy”, “biofuel + policy”, “energy + policy”, “environment + policy”, “policy coherence”, “policy domains”, “policy + dimension”, “biogas + development”, “biogas + conditions”, “biogas + regulations” and “biogas + framework”. The analysis focused on literature that had a direct connection with biogas. This narrowed down the number of articles and reports considerably, from a few thousand to around 200. After scrutinizing the selected articles and reports for mentions of where, how or when policies affect biogas solutions, this number was further reduced.

International overviews and policy documents were in many cases found to be more relevant for the purpose of this study than national studies, which often have a more local focus and are sometimes not available in English. However, a survey focusing on seven selected countries was carried out to gain a deeper insight into the institutional conditions for biogas solutions and to verify and exemplify results from the broader overview. The selection of these countries—Canada, Denmark, Finland, France, Germany, Italy and Sweden—was based on their recent biogas production development and changes in biogas policy. Results from this survey were also used in a comparative study between different countries, where the scope was not limited to the EU (hence the inclusion of Canada) [37]. Four interviews were conducted, with representatives for the Finnish Biogas Association (now part of the Finnish Bio-cycle and Biogas Association), the Italian Biogas Consortium, the German Biogas Association and the Canadian Biogas Association. The interviews were carried out in a semi-structured way, with a set of questions complemented by follow-up questions when

---

1 For sake of simplicity, policies influencing biogas solutions will be referred to as “biogas policies”, even though they are not always exclusively or explicitly directed towards biogas.
needed. The interview form is found in Appendix B. All interviews were done via phone or web platforms for voice communication and the recordings were then transcribed and analyzed. The interviewees were offered anonymity in publication.

The quality of data should, according to Batini et al. [38], be evaluated on (at least) the accuracy, completeness, consistency and timeliness of the data. By comparing the information from several mutually independent sources, it was concluded that the information retrieved through the literature review and the interviews in this study is indeed accurate. Several reports were found to share the same view on the various issues studied, confirming and complementing rather than contradicting each other, thus providing a very consistent basis for the analysis. In terms of timeliness, the literature basis for the analysis mainly included articles and reports from the last decade (2010–2019), and the interviews were conducted during 2019–2020. Finally, the reviewed literature and the interviews conducted were considered to provide a sufficiently large and broad material to fulfill the aims of the study and to justify its conclusions. Many of the reviewed articles and reports comprised broad overviews in themselves, thus providing a good basis for the type of general conclusions that were required for this study.

2.2. Data analysis and construction of model

The analysis of literature and interview transcripts had two purposes: firstly, to identify dimensions and characteristics of biogas policies and come up with an appropriate model to describe these; and secondly, to identify how policies affect or can affect the development of biogas solutions.

In order to achieve this, a qualitative analysis of the literature and the interview transcripts was undertaken, scrutinizing the material for the interaction between policies or policy instruments and biogas solutions. Descriptions of policy types and their characteristics were noted, as well as reports on in what way they influence biogas solutions. Moreover, descriptions of the positioning of biogas policies in terms of sectors or administrative levels were analyzed.

As the aim of this study is to provide a generic model for describing and categorizing biogas policies, the data analysis did not go into the policy situation in specific countries or regions. However, the interviews as well as country-specific policy studies were used to exemplify general conclusions from the literature review.

3. Results and discussion

Based on the literature review and the interviews, the following dimensions or categories of biogas policies were identified:

1) Type of policy instrument
2) Administrative area where policies are valid
3) Administrative level, from local to global
4) Part of the biogas value chain that is targeted
5) Temporal change and continuity

Table A.1 (Appendix A) lists a number of biogas policies, categorized according to this model.

The literature on biogas policies gives support to this model in different ways, although only in implicit and fragmented ways. Specifically, it is often possible to find mentions alluding to category 2 and 3. Kampman et al. [4] mapped the policies and support schemes in the EU, both on the union level and for individual member states (category 3). EU level policies influencing biogas were categorized by the issues they address (Renewable energy, Climate change, Agriculture, Waste and Natural gas), while national support schemes were identified by sector (Electricity, Heat and Transport) (category 2). In the BIOSURF project, Barré et al. [30] investigated policies regarding biogas in six EU countries and on EU level (category 3), categorizing them into different policy areas (category 2) and describing how they are intended to affect biogas solutions (category 4). They tried to sort policies into one or more of the following categories: Sustainability, Non-discriminatory access to the grid, Mass-balance, Transport, Emissions, Biowaste and Digestate. In a report from the SYSTEMIC project, Hermann and Hermann [8] conducted a review of regulations governing AD and nutrient recycling in EU member states and on EU level (category 3). At the EU level, they differentiated between policies, regulations and directives, and for different countries they described the main supportive and restrictive regulations (category 1). Their report also includes examples from anaerobic digestion plants in European countries, describing how they are affected by regulations regarding substrates, nutrients, waste management and wastewater treatment on different levels (category 2/4).

The Record Biomap project provided an overview of biogas policy implementation in European countries, noting significant variations on a national level [31]. In the supplementary material of this report, regulations are categorized according to if they are directed towards substrates, waste handling, construction, products (digestate, electricity, heat and biomethane), environment or economy (category 2/4). Lieu et al. [34] studied policy mixes regarding biofuels in UK, coupling national policy instruments to the governing EU directives. They identified six policy areas where UK biofuel policies could be placed: Energy and Climate, Agriculture, Air, Waste/resource use, Water and Biodiversity (category 2). Several studies, including Kampman et al. [4], Hermann and Hermann [8] and many others, also mention the role of the temporal dimension of biogas policies (category 5). More examples and details on the different dimensions are provided in sections 3.1-3.5.

While the focus in this study is set on biogas policy, it could be possible to apply similar models to other policy frameworks as well, for example within different areas of renewable energy. The outline of the policy dimensions—such as the relevant administrative areas—would then vary depending on the subject. However, this lies beyond the scope of this study.

3.1. Type of policy instrument

Firstly, there are different ways to categorize policy measures and instruments. Kuhndt et al. [39] describe five types of policy instruments: Economic, Regulatory, Research and educational, Cooperation and Informational. Others often emphasize three policy instrument categories in connection with environmental policy: Economic, Regulatory and Voluntary instruments, although the exact terminology may differ. Rhodes et al. [40] presented this categorization, although they used the

| Table 1 | Categorization of policies according to the model regulatory/economic/voluntary; enforcing/encouraging. |
|-----------------|-------------------------------------------------|
| **Enforcing**   | **Legislation**                                 |
|                 | **Directives**                                 |
|                 | **Standards**                                  |
|                 | **Goals**                                       |
| **Encouraging** | **Subsidies**                                   |
|                 | **Green certificates**                          |
|                 | **Procurement**                                 |
| **Regulatory**  | **Taxes**                                       |
| **Economic**    | **Green certificates**                          |
| **Voluntary**   | **Education**                                   |
|                 | **Information**                                 |
|                 | **Cooperation**                                 |
|                 | **R&D**                                         |


term “Market-based” instead of “Economic”. Goulder and Parry [41] called Economic and Regulatory instruments “Incentive-based” and “Direct regulatory” instruments, respectively. Others have used yet other nomenclature for a similar categorization: “Demand-pull” and “Technology-push” instruments [42–46]. Engdahl [47] compared biogas policies in Sweden, Germany and Spain, dividing incentives for biogas solutions into “Economic”, “Knowledge” and “Additional benefits”.

In Table 1, a two-dimensional categorization is used. Firstly, policies and policy instruments can be either regulatory, economic or voluntary. Regulatory instruments include legislation, directives, standards and goals, while economic incentives can be taxes, tradable certificates, procurement or different kinds of subsidies. Voluntary policy instruments include for example education, information, cooperation and research and development. Secondly, a distinction is made between policy instruments that are supportive (“Encouraging”) and those that are commanding or restrictive (“Enforcing”). While Rhodes et al. [40] place subsidies under “Voluntary”, this additional dimension takes into account that subsidies are in fact an economic instrument, although not compelling. The use of green certificates or “cap-and-trade” is an economic instrument that falls under both “Encouraging” and “Enforcing”; it is encouraging for actors who reduce environmental impact and have certificates to sell, and enforcing towards those who are not able to do that, and have to buy certificates from other actors. Regulatory instruments are usually “Enforcing”, although to different degrees. For example, “Goals” are less compelling than “Legislation” and could in some cases be considered to rather have an “Encouraging” function. Voluntary instruments are by definition only “Encouraging”.

3.2. Administrative areas

Spanning across several sectors, biogas solutions are affected by many different administrative areas. Vasco-Correa et al. [48] describe three policy areas related to anaerobic digestion: renewable energy, agriculture and waste management. Other authors identify even more areas that influence biogas solutions, for example Rogstrand [31] and Lieu et al. [34]. In Finland, biogas issues are handled by five different ministries: the ministries of Environment, Agriculture and Forestry, Economy and Labor, Transport, and Finances [49]. This type of structure is not unique to European countries; according to Xue et al. [50], biogas policies in China are found under ministries for Finances, Ecology and Environment, and Agriculture and Rural Affairs, as well as the State Council and the National Development and Reform Commission. Such a wide division of administrative responsibility makes policy coherence in the biogas sector quite challenging, as indeed in other bioenergy sectors [33]. The different administrative units involved are not necessarily aware of the interlinkages to other areas and the benefits that biogas can create there [51].

Fig. 2 illustrates eight administrative or policy areas that in various ways influence biogas solutions. While the use of biogas or biomethane mainly concern energy and in some cases transport, biogas production is often influenced by policies on waste handling, waste water treatment, environment and agriculture, and the use of digestate from anaerobic digestion is a matter for environmental and agricultural policies. Construction regulations set the frames for creation of infrastructure for biogas and biomethane, and all processes are to some extent dependent on economic incentives. In many cases, biogas solutions are influenced by policies and policy instruments indirectly, without being explicitly targeted, which makes the policy landscape even more difficult to define. For example, regulations against landfilling of organic waste favors anaerobic digestion as an alternative treatment method, and taxes on non-renewable energy improve the conditions for biogas and other renewable energy carriers.

3.3. Administrative levels

The administrative policy levels concerning biogas solutions are illustrated in Fig. 3. The figure includes examples of policies existing on global, EU, national and regional/local level. This type of division describes the vertical dimension of biogas governance, in accordance with generic policy theory [52]; the regional and local level is part of the national policy domain, and so on. This image also serves to illustrate the interactions between different administrative levels, which can go in both directions [53]. Policy interaction can also occur horizontally, for

![Fig. 2. Examples of policies affecting biogas solutions within 8 different administrative areas: Energy, Environment, Waste, Water, Agriculture, Transport, Economy and Construction.](image-url)
example between two countries or two municipalities. Lieu et al. [34] found that the UK biofuel policies had been influenced not only by EU policies, but also by biofuel policies in other countries such as the US.

Overarching international goals and agreements set the agenda for questions of global concern, such as climate change and other sustainability issues. They do not, however, prescribe specific solutions for addressing these problems, and there is often no substantial consequence for not complying with common goals. Since global goals are set through discussions between nations with varying political agendas and ambitions, there are often countries that go beyond the common goals, for example by setting more ambitious goals concerning the share of renewable energy.

The EU provides a basis for common policy strategies in Europe. There is, for example, a common policy framework on agriculture for all EU member states, the Common Agricultural Policy. Biogas solutions are influenced by some of these policy frameworks, but are not the focal point of any of them. In other words, there is no “common biogas policy” in the EU, but biogas solutions are indirectly affected by many EU policies. The EU can set common minimum levels for all member states to comply with, provided that a majority can agree on such levels. Currently, there are no such agreements for production or use of biogas, as noted by Rogstrand et al. [31]. EU level policies are often supported by regulatory instruments, EU directives, to be implemented in the national legislation in the member countries. But EU also has some possibility to use economic instruments, e.g. the subsidies for agriculture and support of different environmental actions within member states, and EU is quite active supporting voluntary actions via networking. Through the Renewable Energy Directive and Fuel Quality Directive, EU strongly influences the quality standards of different renewable fuels via e.g. specified Sustainability Criteria [54–56].

The national level is characterized by the possibility of using strong enforcing policy instruments, not least economic instruments like taxes. EU member states also have some independence to form their own standards and to set requirements that are stricter than the common minimum levels. For example, support schemes and approved substrates for biogas may differ a lot between different countries [8,31]. The goals and strategies for achieving increased production and use of biogas can also look very different, due to varying production conditions, demand situations and policy traditions. Energy security is a strong driver in many countries, while it is a non-issue in others. In countries with an abundance of domestic energy resources, energy security is seldom a driver for biogas production. This was noted by Wilkinson [57] in a comparison between Germany (energy importer) and Australia (energy exporter). In Germany, a long-term strategy to become less dependent on fossil energy sources has been a key driver for the development of biogas solutions [58]. Similarly, Kim [59] found that countries that are rich in oil resources are less prominent in energy efficiency innovations in transport. Canada is another example, where availability of cheap fossil-based fuels constitutes a hurdle for renewable alternatives [60]. On the other hand, in countries that profit from exporting renewable energy, like Denmark, being a net exporter is not necessarily a barrier against biogas development [51].

Biogas solutions often have a strong local foundation, connected to a specific farm, industrial facility, landfill or wastewater treatment plant. In many cases, production of biogas through anaerobic digestion has emerged as a waste handling or wastewater treatment technology, often incentives or other policies to stimulate the growth of biogas production. In Germany, a long-term strategy to become less dependent on fossil energy sources has been a key driver for the development of biogas solutions [57] and coordination of efforts [49,60,61]. Lindfors et al. [62] argued that a bottom-up approach could in fact be the most effective way of furthering the development of biogas production and use, focusing on the local and regional resources and specific actors rather than the overall national biogas potential. In the end, many decisions concerning biogas, from building permits to choices of propulsion systems for public transportation, are made at a local or regional level. Thus, there can be substantial variation between different municipalities and regions when it comes to development of biogas solutions; even more so perhaps in countries with a strong federal governance. In Canada, for example, only a handful of the country’s provinces and territories have had economic incentives or other policies to stimulate the growth of biogas production [60]. In Italy, some provinces offer financial support to construction of biogas plants through the European Rural Development Programmes, while in other regions that is not an option [63].
3.4. Targeted part of the value chain

It is furthermore important to address how biogas policies and policy instruments relate to different parts of the biogas value chain (Fig. 4). This includes looking into policies that have an indirect effect on biogas solutions, which is often the case. Hagman and Eklund [26] identified more than 30 benefits with biogas solutions—some of which are listed in Table 2—and found that biogas can contribute to reaching all 17 of the UN sustainable development goals. These benefits are connected to different elements of biogas solutions, and by focusing only on one or a few of them some benefits will risk being missed. For example, production of biogas provides a solution for organic waste treatment and wastewater treatment, the use of biogas or biomethane can reduce the life-cycle climate change impact from heat and electricity production (see e.g. Ref. [64,65]) or from transport (see e.g. Ref. [66,67]), and recycling of nutrients and soil carbon can be achieved by using digestate from anaerobic digestion as a fertilizer (see e.g. Ref. [68,69]). There are also more intangible benefits that are not as clearly tied to a specific part of the value chain, such as increased employment, economic growth and rural development [26] (not included in Table 2). In principle, it can be sufficient to focus the support on one part of the value chain, e.g. subsidizing the utilization of biogas to stimulate the demand and thereby increase the production. However, moving towards an international biogas market, such an approach might not be sufficient to stimulate domestic production, but only lead to increased imports. This has been the case in Sweden, where an exemption from carbon and energy taxes has stimulated the demand for biogas, which has increasingly been met by imports from Denmark [61]. Thus, Sweden gets the benefits of using biogas, while Denmark gets the benefits of producing it. Disregarding policies on production would also leave biogas producers without guidance on how to design production systems. Many European countries are steering away from the use of energy crops in biofuel production favor of waste products [21], which in biofuel regulations is promoted as a more sustainable alternative (see e.g. Ref. [70,71]). Fig. 4 presents some examples of policies influencing production, distribution and use of biogas or digestate. Table A.1 (Appendix A) provides additional examples on how policies affect biogas solutions by addressing different parts of the value chain, including different production technologies and areas of use.

![Fig. 4. Examples of policies directed towards different parts in the value chain of biogas: Production, Distribution and Use.](image)

![Fig. 5. Illustration of the temporal dimension of policies, showing that policies can be long-term (e.g. “Policy A”) or short-term (e.g. Policy D), introduced or discontinued, and can reappear (“Policy C”) or change character over time (“Policy B”).](image)

| Production | Use of biogas/biomethane | Use of digestate |
|------------|--------------------------|-----------------|
| Wastewater treatment | Renewable heat and power | Nutrient recirculation |
| Organic waste treatment | Renewable vehicle fuel | Improved soil structure |
| Increased resource efficiency | Reduced greenhouse gas emissions | Increased yield from agriculture |
| Reduced methane emissions from landfills | Reduced emissions of nitrogen oxides | Reduced use of mineral fertilizer |
| Reduced methane emissions from manure | Reduced emissions of particulates | Reduced odor from agriculture |
| National self-supply of energy | Reduced noise from vehicles | Facilitates organic farming |

Table 2
Categorization of benefits with biogas solutions into different parts of the value chain. Adopted with permission from Hagman and Eklund [26].
3.5. Temporal change and continuity

Finally, there is a temporal dimension of policies, as policies and particularly policy mixes are often dynamic and variable. As illustrated in Fig. 5, policies may be introduced or discontinued, and can reappear or change character over time. Continuity and stable conditions are frequently described as key for further development of biogas solutions. Several studies have pointed out unpredictable and volatile policies as one of the main barriers to the development of biogas production and use (see e.g. Ref. [4,6,8,9,11,72–74]). Particularly, uncertain economic conditions are a threat to investments and the longevity of biogas plants, as indeed for other bioenergy technologies [14]. In some cases, long-term contracts on e.g. feed-in-tariff for biogas provide stable and foreseeable conditions over decades. In Italy, the support scheme recently changed from a feed-in-tariff system for electricity from biogas to subsidies being given only to biomethane production for vehicle fuel [63]. However, the plants producing biogas for electricity can rely on the old subsidy system (before 2020) will continue to receive support for 20 years [58], and biogas producers in Ontario, Canada, will have a fixed price on the electricity they sell for 20 years even though the feed-in-tariff program ended in 2017 [60]. While such continuity in support systems has provided a stable basis for a rapid increase of biogas production in e.g. Germany [58] and Italy [63], it is also connected to risks of creating lock-in effects that hinder further development. Although both Germany and Italy have intentions to use biogas in the transport sector, biogas producers in these countries are not likely to start producing biomethane for vehicles if they are tied to contracts to produce electricity for another 10–20 years. Sweden, on the other hand, has a more flexibility-oriented approach to policy. For example, the regulation regarding tax reduction for “environmentally friendly” vehicles changed dramatically in 2013 from an overall limit on CO₂ emissions to a system where the limit was more generous for heavy vehicles and stricter for light vehicles [76], thus favoring large diesel cars with relatively efficient engines. For biogas and other biofuels that could easily comply with the old limits, this change was a great drawback. This vehicle tax system has now been changed again, increasing the tax for all gasoline- and diesel vehicles and subsidizing gas vehicles and other cars with very low CO₂ emissions, with the intention of giving biofuels and electric vehicles a boost [77].

The temporal dimension is not included in Table A.1 (Appendix A), and this table does not describe a specific case.

4. Conclusions

In this article, the institutional conditions for biogas solutions have been described by identifying the dimensions and characteristics of biogas policies. The proposed model divides biogas policies into five dimensions: type of policy, administrative area, administrative level, which part of the value chain that is addressed, and how policies change over time. This multidimensional model reflects the complexity of the conditions for biogas solutions and constitutes a platform for describing, discussing and developing biogas policies. It also shows the importance of interaction and cooperation between different administrative areas and levels, and of considering the whole value chain of biogas solutions in policy making. The proposed model can contribute to a common understanding of how policy mixes concerning biogas can be constructed, and consequently facilitate the development of biogas solutions. A possible implementation of the model could be to analyze the state and development of biogas policies in different countries or regions, or in the EU.

The fact that biogas solutions involve so many different administrative sectors may infer a risk for biogas to become “somebody else’s problem” and that the governance will be diffuse and ineffective. To some extent this is already the case, which is evident from the literature on biogas, especially considering the extent of indirect policy influence. If the technical potentials of biogas production are to be achieved, with all the benefits that would bring, a more holistic view on biogas solutions from policy makers is most likely required, as well as improved coordination between sectors.

Biogas can, as shown in other studies, contribute to coping with several sustainability challenges, through different parts of its value chain. Harvesting all the benefits of biogas requires a comprehensive view and adequate policies for the whole value chain, including utilization of digestate. A too narrow focus can lead to some benefits being moved away from the targeted area, e.g. to another country or region, or being lost altogether.

The lack of temporal continuity and clear political direction is a challenge for the development of biogas solutions. Biogas producers require a reasonably low risk on their investments, which could either be secured through long-term contracts or some form of insurance. However, rigid systems are also less flexible and difficult to adapt to changing conditions. Still, a broad political consensus on the value and importance of biogas solutions and coordination across administrative levels would mean increased stability and improved conditions for biogas.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This research has received funding from the Swedish Biogas Research Center (BRC), which in turn is funded by the Swedish Energy Agency [grant number 35624-3]. We would also like to thank the interviewees for providing valuable inputs to the study.
Appendix A. Categorization of biogas policies

Table A.1
Categorization of policies affecting biogas solutions, and relation between policies and areas within biogas solutions. “x” marks the areas where the policies belong, and their impact on biogas solutions is indicated with “+” (positive), “-” (negative) or “+/−” (uncertain effect, can be either positive or negative).

| Policy                                                      | Policy type | Administrative level | Administrative area |
|-------------------------------------------------------------|-------------|----------------------|---------------------|
|                                                            | Regulatory  | Economic             | Enforcing           | Encouraging         | Global | EU | National | Regional/local | Energy | Environment | Waste | Water |
| ABPR (Animal By-Product Regulation)                         | x           | x                    | x                   |                     |        |    |          |                |        |             |       |       |
| Biogas/biomethane certificate of origin                     | x           | x                    | x                   |                     |        |    |          |                |        |             |       |       |
| Biogas register                                             | x           | x                    |                     |                    |        |    |          |                |        |             |       |       |
| Biogas/biomethane tax exemption                             | x           | x                    |                     |                    |        |    |          |                |        |             |       |       |
| Blending quota                                              | x           | x                    |                     |                    |        |    |          |                |        |             |       |       |
| CAP (Common Agricultural Policy)                            | x           | x                    |                     |                    |        |    |          |                |        |             |       |       |
| Credits for carbon reduction and carbon trading             | x           | x                    |                     |                    |        |    |          |                |        |             |       |       |
| Credits for nutrient load reduction                         | x           | x                    |                     |                    |        |    |          |                |        |             |       |       |
| Digestate certification                                     | x           | x                    |                     |                    |        |    |          |                |        |             |       |       |
| Directive on the landfill of waste                          | x           | x                    |                     |                    |        |    |          |        |             |       |       |
| Double counting of biogas from waste allowed                | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Eco-friendly vehicle standard                               | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Feed-in-tariff for biomethane                               | x           | x                    |                     |                    |        |    |          |                |        |             |       |       |
| Feed-in-tariff for heat/electricity from biogas/biomethane  | x           | x                    |                     |                    |        |    |          |                |        |             |       |       |
| Fixed handling time for construction project applications    | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Fossil energy taxes                                         | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| FQD (Fuel Quality Directive)                                | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Goal on energy security                                     | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Goal on food security                                       | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Goal on increased share of renewable energy                 | x           | x                    | x                   |                    |        |    |          |                |        |             |       |       |
| Goal on number of gas vehicles                              | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Goal on reduced CO₂-emissions                               | x           | x                    | x                   |                    |        |    |          |                |        |             |       |       |
| Green zones                                                 | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Guidelines for construction of biogas/biomethane plants     | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Guidelines for construction of filling stations             | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Low-interest loans for gas vehicles                         | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Nitrates Directive                                          | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Overcompensating support allowed                            | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Procurement directed towards gas vehicles                   | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Procurement directed towards biogas/biomethane              | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Production support for heat/electricity from biogas/biomethane | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| RED (Renewable Energy Directive)                            | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Reduced vehicle tax for gas vehicles                        | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Reduction quota                                             | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Regulations on distribution and spreading of digestate      | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Regulations on heat/electricity from biogas/biomethane      | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Requirement to provide biofuels on filling stations         | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Restrictions on landfill of organic waste                  | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Restrictions on use of energy crops                         | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Restrictions on use of waste substrates                     | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Small project handling priority                             | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Standard for gas grid distribution                          | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Standard for vehicle gas                                    | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Subsidies for converting vehicles to gas propulsion         | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Support to construction of biogas/biomethane plants         | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Waste Framework Directive                                   | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |
| Water Framework Directive                                   | x           | x                    |                     |                    |        |    |          |              |        |             |       |       |

M. Gustafsson and S. Anderberg

Renewable and Sustainable Energy Reviews 135 (2021) 110200
| Administrative level | Administrative area | Targeted area in the value chain |
|----------------------|---------------------|----------------------------------|
| National             | Agriculture Transport | Production Distribution and trade Use |
|                      | Anaerobic digestion Thermal gasification | Use of digestate Biomethane for transport Liquefied biomethane Biogas/biomethane for heat/electricity |
| x                    | +/-                 | +                                |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +/-                 | +                                |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +/-                 | +/-                             |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +/-                 | +/-                             |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +                   | +                                |

| Administrative level | Administrative area | Targeted area in the value chain |
|----------------------|---------------------|----------------------------------|
| National             | Agriculture Transport | Production Distribution and trade Use |
|                      | Anaerobic digestion Thermal gasification | Use of digestate Biomethane for transport Liquefied biomethane Biogas/biomethane for heat/electricity |
| x                    | +/-                 | +                                |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +/-                 | +/-                             |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +/-                 | +/-                             |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +                   | +                                |

| Administrative level | Administrative area | Targeted area in the value chain |
|----------------------|---------------------|----------------------------------|
| National             | Agriculture Transport | Production Distribution and trade Use |
|                      | Anaerobic digestion Thermal gasification | Use of digestate Biomethane for transport Liquefied biomethane Biogas/biomethane for heat/electricity |
| x                    | +/-                 | +                                |
| x                    | +                   | +                                |
| x                    | +/-                 | +/-                             |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +/-                 | +/-                             |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +/-                 | +/-                             |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +                   | +                                |
| x                    | +                   | +                                |

9
Appendix B. Interview form

Interview with representative for [organisation] in [country].

- Please describe the role of [the organisation] in [the country].
- Please describe your role within [the organisation].
- Which sector/s is/are the most important for [the country’s]:
  - Biogas production?
  - Use of biogas?
- Why is it like that? Has it been an intended strategy, or are there other explanations?
- Does [the country] have any official goals for production and use of biogas?
  - If “yes”: What do these goals mean in practice?
  - If “no”: Why is that?
- How are the EU directives and regulations of waste and renewable energy implemented?
- Does [the country] have more ambitious goals than that, or do they stick to the common levels and goals of the EU?
- What do you think have been the most driving factors behind [the country’s] development within:
  - Biogas production?
  - Use of biogas?
  - Have there been any financial incentives involved?
  - Which regulatory incentives are there for biogas production/use?
  - Which factors, in your opinion, have been the most inhibiting for such developments?
- How could/should the development of biogas production and use in [the country] be accelerated even more?
- What type of efforts are needed?
- Where should these efforts be concentrated? Production/use/both/other?
- What does the competition for biogas look like in [the country]?
- Other fuels/energy carriers? Fossil/renewable?
- Other waste treatment methods?
- Which factors are important on the market/s where biogas competes?
  - Financial/technology/policy/knowledge/other?
- What role does natural gas have in the development of biogas production and use in [the country]?
- Is it a competitor or a bridge for biogas?
- Is there a gas infrastructure in place that facilitates the introduction of biogas?

References

[1] Scarlat N, Dallemend J-F, Fahl P. Biogas: developments and perspectives in europe. Renew Energy 2018;129:457–72. https://doi.org/10.1016/j.renene.2018.03.006.

[2] EuroObserv-ER. Biogas barometer. 2017.

[3] EuroObserv-ER. Biogas barometer. 2010.

[4] Kampman B, Leguijt C, Scholten T, Tallat-Kelpsaite J, Brückmann R, Maroulis G, et al. Optimal use of biogas from waste streams - an assessment of the potential of biogas from digestion in the EU beyond 2020. European Commission; 2016.

[5] WSP. Realisering biogaspotential i Sverige år 2030 genom röntgen og förösning. 2013.

[6] Huttunen S, Kivimaa P, Virkamaa P. Addressing uncertainty in decarbonisation policy mixes: lessons learned from German and European bioenergy policy. Energy Res Soc Sci 2017;33:95–105. https://doi.org/10.1016/j.erss.2017.02.044.

[7] Kuhnt H, Prenske A. It’s not right, but we do it. Exploring why and how Czech farmers become renewable energy producers. Biomass Bioenergy 2016;87:26–34. https://doi.org/10.1016/j.biombioe.2016.02.007.

[8] Torrijos M. State of development of biogas production in europe. Procedia Environ Sci 2016;30:881–9. https://doi.org/10.1016/j.proenv.2016.07.045.

[9] Linnqvist T, Anderberg S, Ammenberg J, Sandberg T, Grönkvist S. Stimulating biogas in the transport sector in a Swedish region – an actor and policy analysis with supply side focus. Renew Sustain Energy Rev 2019;113:109269. https://doi.org/10.1016/j.rser.2019.109269.

[10] Coni C, Mancusi ML, Sanna-Randaccio F, Sestini R, Verdolini E. Transition towards a green economy in Europe: innovation and knowledge integration in the renewable energy sector. Res Pol 2018;47:1996–2009. https://doi.org/10.1016/j.respol.2018.07.007.

[11] McCarthy T, Sesmero J. Uncertainty, irreversibility, and investment in second-generation biofuels. BioEnergy Rev 2015;8:687–85. https://doi.org/10.1007/s12155-014-9549-y.

[12] Hosseini SE, Wahid MA. Development of biogas combustion in combined heat and power generation. Renew Sustain Energy Rev 2014;40:688–74. https://doi.org/10.1016/j.rser.2014.07.001.

[13] Salvador R, Barros MV, Rosario JGDPD, Piekarski CM, Luz LM, Francisco AC. Life cycle assessment of electricity from biogas: a systematic literature review. Environ Prog Sustain Energy 2019;38:13133. https://doi.org/10.1002/ep.13133.

[14] Ahamed M, Moghaddam H, Abegren S, Holteberg C, Nordberg Å. End-use efficiency and global warming potential of biogas-based fuels from a life cycle perspective. Fuel Process Technol 2015;132:74–82. https://doi.org/10.1016/j.fuproc.2014.12.014.

[15] Lyng K-A, Brekke A. Environmental life cycle assessment of biogas as a fuel for transport compared with alternative fuels. Energies 2019;12:532. https://doi.org/10.3390/en12030532.

[16] Chen S, Chen B, Song D. Life-cycle energy production and emissions mitigation by comprehensive biogas-digestate utilization. Bioresource Technol 2012;114:357–64. https://doi.org/10.1016/j.biortech.2012.02.084.

[17] Yasar A, Nazir S, Tabinda AB, Nazar M, Rasheed R, Afzal M. Socio-economic, health and agriculture benefits of rural household biogas plants in energy scarce developing countries: a case study from Pakistan. Renew Energy 2017;108:19–25. https://doi.org/10.1016/j.renene.2017.08.066.

[18] EBA. European biogas association statistical report: 2019 European overview. 2020. Brussels, Belgium.

[19] Hagman L, Blumenthal A, Eklund M, Svensson N. The role of biogas solutions in sustainable bioinfrastructures. J Clean Prod 2018;172:3982–9. https://doi.org/10.1016/j.jclepro.2017.03.180.

[20] Rosenow J, Kern F, Rogge K. The need for comprehensive and well targeted policy mixes to stimulate energy transitions: the case of energy efficiency and conservation. Environ Pol Governance 2012;22:395–410. https://doi.org/10.1080/16840221203389204.

[21] Kuhnt H, Prenske A. It’s not right, but we do it. Exploring why and how Czech farmers become renewable energy producers. Biomass Bioenergy 2016;87:26–34. https://doi.org/10.1016/j.biombioe.2016.02.007.

[22] Lindeborg A, Feir R, Eklund M, Ammenberg J. Assessing the potential, performance and feasibility of urban solutions: methodological considerations and learnings from biogas solutions. Sustainability 2019;11:3756. https://doi.org/10.3390/su11113756.

[23] Reimann J, Kuhl M, Machiba T, Herrndorf M, Muchorowski T, Villar A, Liedtke C, et al. Circular economy: evaluation of sewage sludge biogas solutions. Resources 2019;8:91. https://doi.org/10.3390/resources8020091.

[24] Hagman L, Eklund M. The role of biogas solutions in the circular and bio-based economy. Biogas Research Center; 2016.

[25] Dada O, Mbohwa C. Energy from waste: a possible way of meeting goal 7 of the sustainable development goals. Mater Today: Proceedings 2018;5:10577–84. https://doi.org/10.1016/j.matpr.2017.12.590.

[26] World Biogas Association. Factsheet 3: how to achieve the sustainable development goals through biogas. 2017.

[27] Deremince B, Scheidt S, Stambskaja J, Wellinger A. Data bank with existing incentives and subsequent development of biogas plants compared to national targets. Biogas Action; 2017. Grant Agreement no 691755.

[28] Barre C, Przadka A, Kovacs A, Collins D, Kirchmayr F, Münch J, et al. Inventory and analysis of the EU and national regulatory framework. Grant agreement no 646533 BIOS 2016.

[29] Rogstrand G. Overview on administrative and legal conditions as well as on financial and other support programs, for small to medium scale biomethane production and supply. Grant Agreement no 691911 Record Biomap 2018.

[30] Kuhndt M, Machiba T, Herrndorf M, Muchorowski T, Villar A, Liedtke C, et al. A level playing field for the European biogas and biomethane markets - case of The Netherlands and Germany: policy environment, key differences and harmonisation issues. 2015.

[31] de Gorster H, Just DR. The welfare economics of biofuel tax credits and mandates. In: Khanna M, Scheffran J, Ziberman D, editors. Handbook of bioenergy economics and policy; 2010.

[32] Lieu J, Spirtzdaal N, Alvarez-Tino ro R, van der Gaast W, Tuerk A, van Vliet O. Evaluating consistency in environmental policy mixes through policy, stakeholder, and contextual interactions. Sustainability 2018;10:1886. https://doi.org/10.3390/su10061896.

[33] Kuhndt M, Machiba T, Herrndorf M, Muchorowski T, Villar A, Liedtke C, et al. Policy instruments for resource efficiency – towards sustainable production and...
