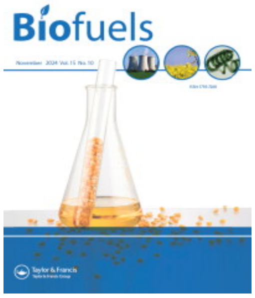

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Policy risks in the biogas sector – the case of Sweden

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ABSTRACT

Policy is decisive to stimulate biogas expansion; but policy-related factors may also inhibit the development. This study explores policy risks in the Swedish biogas sector and identifies strategies to mitigate these risks. The study is based on three workshops and a survey with participation of biogas stakeholders. The findings reveal that two major policy risks significantly impact the Swedish biogas sector: the 'lack of long-term strategies' and the 'long and complicated permitting processes.' 'Limitations of permitted feedstocks' and 'limited system perspective—benefits of circular economy and sustainable food system' are also among the most probable risks. More clearly defined roles for authorities at different administrative levels and the promotion of life cycle perspectives are critical to mitigate these risks. The research emphasizes that both EU and national governments play vital roles in reducing policy risks through predictable and long-term biogas strategies. Without these interventions, the potential of the Swedish biogas sector may remain underutilized.

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KEYWORDS

Policy risk; biogas; biomethane; institutional conditions

Introduction

Biogas contributes importantly to renewable energy supply and greenhouse gas emission reduction by using waste and residue streams as input and replacing fossil energy [1]. In recent decades, biogas production and use have increased in Europe. Between 2000 and 2022, the production in the EU-27 grew more than 10 times, from 16 TWh to 183 TWh [2]. This dramatic growth was mainly driven by national policies and financial support systems of different types [3]. However, it is also possible to connect slow or lacking growth to policy. Studies have shown that short-term, changeable and unpredictable policies pose influential risks in connection with investments in renewable energy projects [4,5]. *Policy risk* refers to uncertainties in regulations and policies that impact businesses and their investment environment [4, 6].

Previous studies have assessed policy risk in connection with renewable energy investments, especially for wind and solar power projects [4,5]. Research has shown that political priorities can influence the availability and affordability of financial support, which, in turn, affects the selection of promising technologies [4]. Vogl et al. [5] quantified the impact of policy risks on renewable energy investments, demonstrating that such risks can significantly affect the potential returns and the risk of losing money. They also found that cross-country diversification in a portfolio of wind farms can reduce overall investor risk [5].

However, biogas extends beyond renewable energy due to the multiple benefits generated by the entire biogas system. The policies that impact biogas systems span across numerous policy areas. A limited focus on energy support schemes may increase the risk of overlooking important effects resulting from changes in other policy areas [7]. Unstable and short-sighted policies are significant barriers to the use of biogas as fuel in the transport sector or manufacturing industry [8,9] as well as to the broader implementation of biogas as an energy source [10]. While previous studies have identified policy-related barriers to biogas development, they have not differentiated the policy risks posed at different administrative levels. Furthermore, they have not examined policy risks to the whole biogas value chain, instead focusing on specific parts of the value chain (e.g. end-use). Finally, the studies have not explored how different biogas stakeholders can mitigate policy risks. To address these research gaps, this paper aims to identify policy risks in the Swedish biogas sector and propose mitigation strategies. It has been guided by the following questions:

- *What are the policy risks for the Swedish biogas sector?*
- *To what extent do these risks influence the Swedish biogas sector?*
- *How can these risks be mitigated at different levels of governance?*

These questions were approached *via* literature studies and a workshop series with different biogas stakeholders, arranged within Biogas Solutions Research Center (BSRC), a Swedish national competence center on biogas solutions. BSRC includes researchers from Linköping University and the Swedish University of Agricultural Sciences, along with representatives for companies involved in the production, distribution, or utilization of biogas, technology providers,

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and public organizations [11]. The overall structure of the study is inspired by the ISO 31000 risk management guidelines, and built upon four steps: establishing context, risk identification, risk evaluation, and risk mitigation. A policy model for analyzing biogas-related policies developed by Gustafsson and Anderberg [7], including type of policy, administrative areas, administrative levels, targeted part of biogas value chain, and temporal change of policies, is used to categorize and analyze how these risks affect the biogas systems.

The article is structured as follows: 'Background' section introduces the Swedish biogas sector. 'Methods' section presents the overall study process and details for each step. Findings and discussions related to the identified policy risks, evaluation of these risks, and strategies for risk mitigation are presented in 'Results and discussion' section. 'Conclusion' section presents the conclusions.

Background

The energy supply of the Swedish energy system is predominantly based on renewable energy sources such as hydropower, wind power and biofuels complemented by imported nuclear fuels [12]. Fossil fuels are today primarily used for transport and industry [12]. Among the renewable energy sources, biofuels are vital in all final energy consumption sectors; they are used for producing electricity and heat and used as fuels in industry and as well as for transport (Figure 1). In 2022, the total energy supply in Sweden was 548 TWh, with 28% coming from biofuels, including HVO (hydrotreated vegetable oil), bioethanol, biodiesel and biogas [12,13]. 39% of the biofuels were used in industry, 26% for district heating, 13.5% for transport, and 12% for generating electricity [13].

Biogas, as one important representative type of biofuel, has a long development history in Sweden. In the 1940s, it was first introduced in municipal wastewater treatment plants to decrease sludge volumes [14]. The oil crisis in the 1970s increased the interest in biogas techniques to address oil import dependency and environmental concerns [15]. Both industrial and farm-scale biogas plants were established with support from national programs, fostering extensive expertise in optimizing the management and utilization of diverse residues and waste streams [14]. Methane extraction from landfills was introduced in the 1980s [14]. The 1990s witnessed the introduction of large-scale co-digestion, based on organic waste from diverse sources. Since then, biogas production facilities designed to digest various organic substances, including waste from dairy industries, slaughterhouses, and source-separated food waste from households and restaurants have been built in cities all over Sweden [14]. However, since 2015, even though the demand for biogas has continued to grow, domestic production has not increased much (Figure 2). Instead, biogas imports through the gas grid from Denmark have increased dramatically [1][16].

Until the 1990s, the produced biogas in Sweden was predominantly used for local heating. As a response to local pollution issues, there was a shift in the early twenty first century toward prioritizing the upgrading of biogas to biomethane for use as a vehicle fuel [14]. In 2022, 67% of the produced biogas was upgraded to biomethane, of which more than 3/4 was utilized for road transport [17]. Sweden, Denmark and France are the only European countries, where most of the biogas produced is upgraded [18].

The primary support for biogas and biomethane production in Sweden has been tax exemption for biogas and biomethane sales. The tax exemption, as a form of state aid, has required renewed approval from the EU Commission every year, in sharp to contrast to other European countries applying other forms of fixed economic support systems lasting 10 to 20 years. This lack of continuity and predictability appears to have hindered the development of biogas production systems [19]. In response to the stagnation of biogas production, a long-term production support for biomethane, up to a maximum of 30 EUR/MWh, and an additional maximum of 15 EUR/MWh for liquefied biomethane, were introduced in 2022 [20]. As a complement to the new production support, the EU Commission initially approved a continuation of the tax exemption from 2021 to 2030, but this approval was invalidated by the General

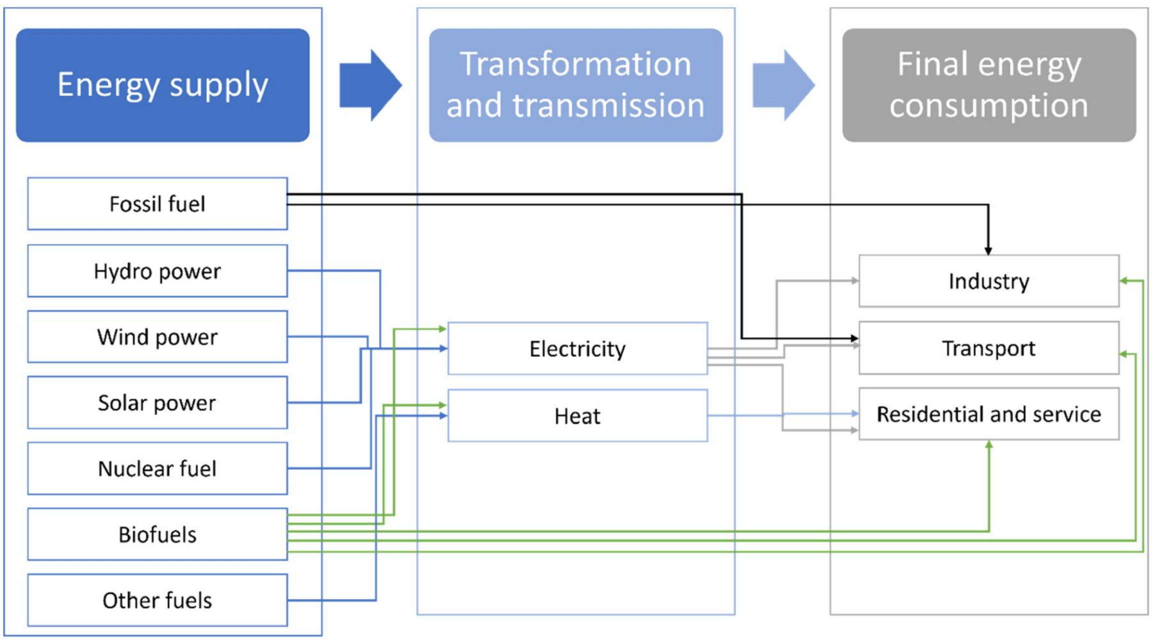

Figure 1. Overview of the Swedish energy system [12].

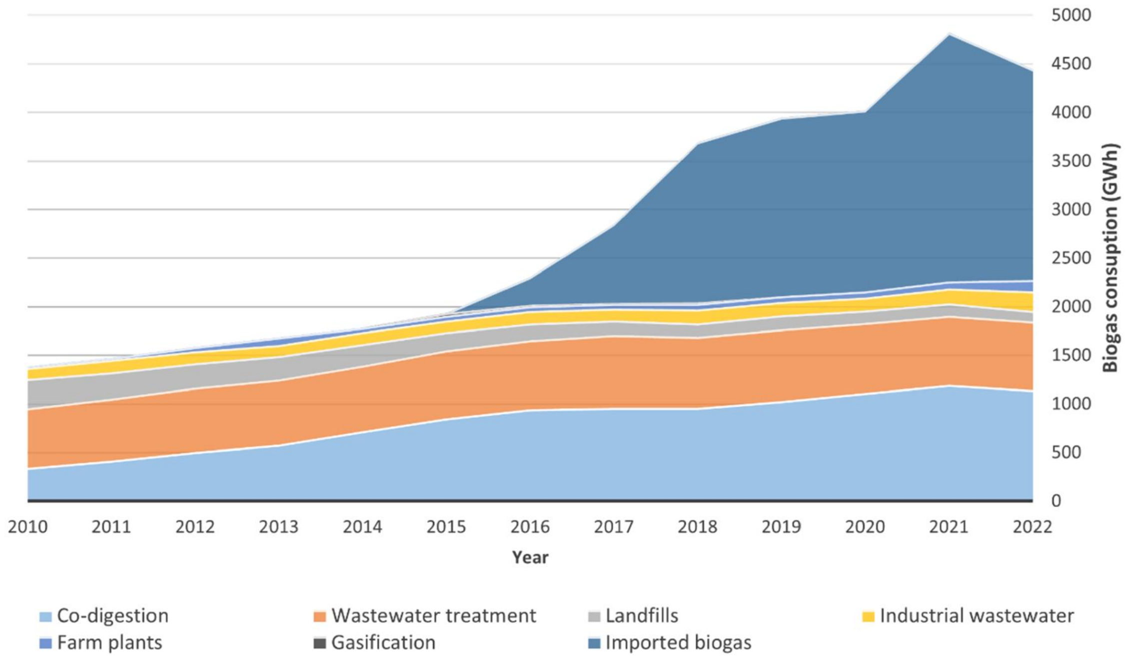

Figure 2. Sources of biogas consumption in Sweden 2010–2022 [17].

Table 1. Overview of the participants in the workshops and the survey respondents.

	Workshop participants			Survey respondents
	WS1	WS2	WS3	
Research group	2	3	3	
Other researchers	6	4	9	9
Municipal representatives	1	1	1	1
County representatives	4	1	2	2
Biogas companies	2	1	1	7
Biofertilizers companies	1		1	
Biogas technology providers			1	1
Waste management companies	1			1
Wastewater treatment companies				1
Food companies				1
Agricultural organization	1	1		
National energy gas association			1	
Total	18	11	19	23

Court of the EU due to a procedural error. According to both the Swedish government and the EU commission the tax exemption will be reintroduced; however, when it can be done remains uncertain [20]. These uncertainties are posing difficult challenges for the Swedish biogas sector.

Methods

The study is based on literature studies, a series of three workshops and a survey with participation of biogas stakeholders. The workshops were organized as a part of Research Area 1 (RA1) within the BSRC. There are five research areas in the BSRC, including RA1: Conditions and strategies for biogas solutions, RA2: The production system, RA3: Digestion processes, RA4: Market and use, and RA5: Sustainability effects of biogas solutions [11]. BSRC provides a valuable platform and a wealth of resources for this study.

All participants and survey respondents came from different organizations participating in the BSRC, including municipalities, regions, biogas producers, biofertilizer companies, as well as universities (Table 1).

The structure of the research process was inspired by the risk management guidelines outlined in ISO 31000, and its four steps establishing the context, risk identification, risk evaluation, and risk mitigation [21] (Figure 3).

Establishing the context

Based on literature studies and previous BSRC work, this study focuses on identifying actual and potential changes and uncertainties in the existing policy landscape for the Swedish biogas sector, instead of dramatic events (e.g. war, pandemics) that are altering the frames.

Risk identification

The aim of the first workshop (WS1) was to identify potential policy risks. It took place in August 2022 and involved 18 participants. Groups of participants proposed potential policy risks related to the Swedish biogas sector, which parts of the biogas value chain these risks impact, and potential measures and actors for risk mitigation. After the workshop, the identified risks were initially grouped according to their characteristics and coded for further analysis. Subsequently, these risks were categorized using the different dimensions of the policy model introduced by Gustafsson and Anderberg [7], including type of policy instrument (e.g. regulatory, economic, or voluntary), administrative levels (from local to EU), administrative areas where policies are valid, which parts of the biogas value chain that are targeted, and temporal change (Figure 4). The biogas value chain (Figure 5) consists of four distinct blocks: feedstock supply for biogas generation, biogas production technology and facilities, use and distribution of biogas and biomethane, as well as the bio-CO_2 market,[2] and the final block deals with the biofertilizer market.

This policy model was developed for analyzing and categorizing biogas policies and should therefore also be applicable to policy risks. The biogas system is influenced by numerous policy domains such as energy, agriculture, economics, environment, and transport, requiring an analytical model that can capture this complexity. Additionally, the

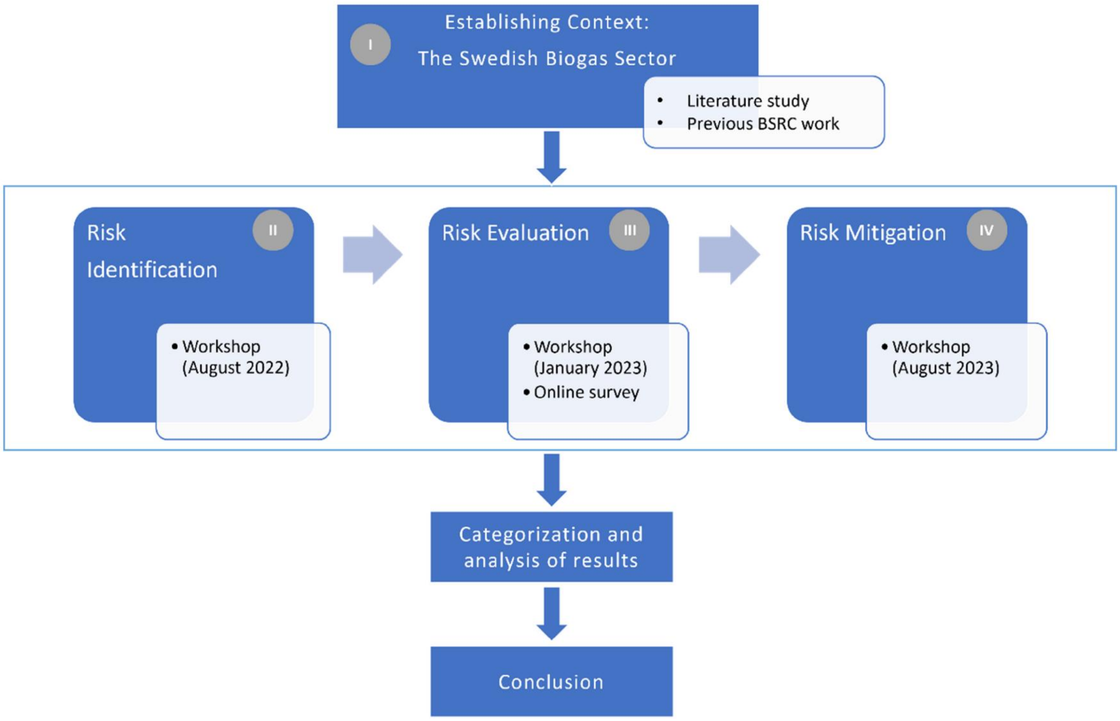

Figure 3. Study process.

Swedish context of the study necessitates accommodating multi-level governance, from local to EU levels. This targeted approach ensures a precise and relevant analysis of the biogas sector in Sweden.

Risk evaluation

The second workshop (WS2) focused on risk evaluation. It took place in January 2023 and had 11 participants (Table 1). Its primary objective was to prioritize the risks identified during WS1. During WS2, participants discussed the impact and probability of the policy risks.

This workshop was followed by an online survey, titled 'Assessment of Policy-related Risks for Biogas Sector in Sweden', which made it possible to collect the views of a broader group of stakeholders. This survey was implemented through *Google Forms* designed for the creation, distribution, and analysis of online questionnaires. Participants were asked to rate the probability and impact of the risks that were identified in WS1. The survey was distributed to a total of 171 BSRC partners and members, resulting in 23 responses. This low response rate can be attributed primarily to the complexity of the topics, posing challenges for those that had not been part of RA1 activities and the workshops, which offered crucial insights to the topic. The respondent distribution mostly mirrors that of previous workshop participants, except for more responses from biogas companies, wastewater treatment companies, and food companies compared to participants in WS2 (Table 1).

The assessment of the probability of the policy risks was conducted using a five-point scale (Table 2). To enhance objectivity and facilitate comparability in the risk assessment process, each point on the scale was associated with a specific meaning.

The impact of policy risks was also assessed on a scale ranging from 1 to 5 (Table 3). In this context, all potential impacts were evaluated in relation to the influence on biogas production, utilization, and the broader development of the biogas sector.

Risk mitigation

Workshop 3 (WS3), held in August 2023 and involving 19 participants (Table 1), was dedicated to risk mitigation. The group discussions focused on identifying strategies to mitigate the identified policy risks within the Swedish biogas sector. Participants were divided into five groups and instructed to discuss strategies from the point-of-view of different actors/governance levels, including the EU, national government, local/regional government, biogas companies, and biogas consumers.

Results and discussion

Risk identification

Table 4 presents a summary of identified policy risks for the Swedish biogas development. These risks are related to: first, difficulties in connection with permitting processes and finding guidance for balancing production potential and practical costs; second, deficiencies in certain strategies or policies for the biogas sector, such as lack of long-term strategies, lack of infrastructure and storage-related policies, and lack of policies for biofertilizer and CO_2; lastly, various limitations, such as limitations on permitted substrates, availability of substrates, competition over substrates and a limited system perspective that hinders the circular benefits of biogas systems.

Difficulties in connection with permitting processes and finding guidance for balancing production potential and practical costs

Social (or socio-political) risk was introduced because participants brought up that local opposition against projects,

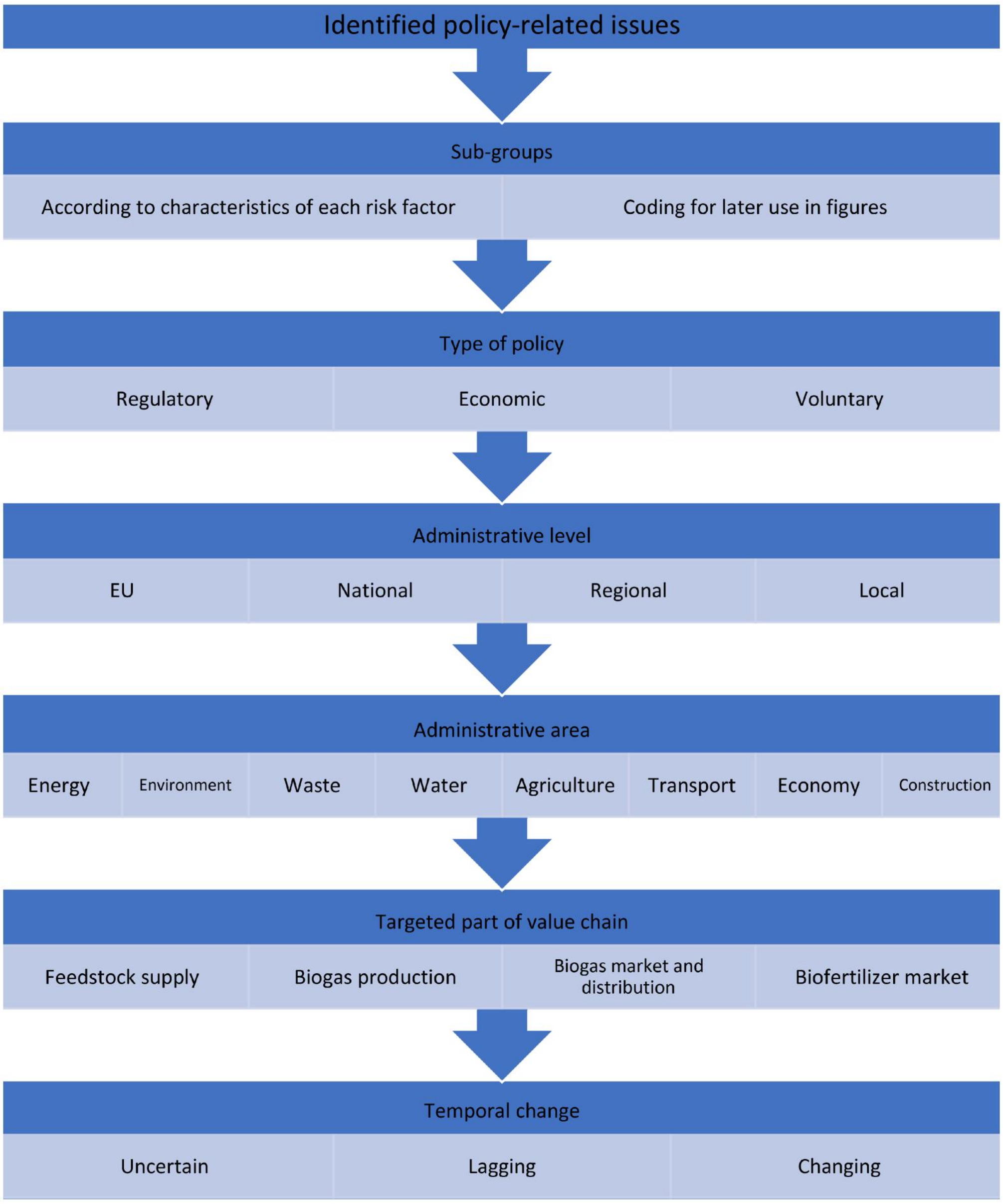

Figure 4. The process of categorization of identified risks.

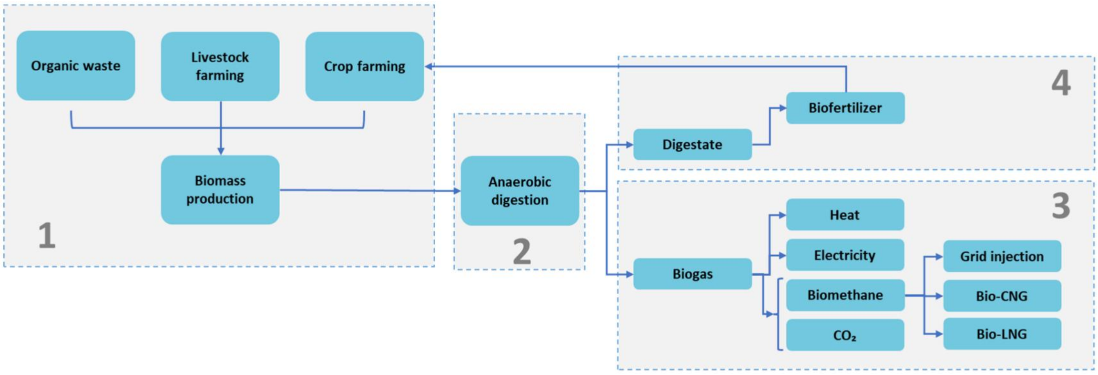

Figure 5. The biogas value chain.

Table 2. Scale of the probability of risks and its characteristics.

Probability	Score	Characteristics of probability
Certain	5	It is an existing barrier.
Highly probable	4	It is very possible that it will happen very soon.
Probable	3	It could happen in the future.
Unlikely	2	It could happen, but only under some certain conditions.
Improbable	1	It will not happen.

Table 3. Scale of the impact of risks and its characteristics.

Impact	Score	Characteristics of impact
Maximum	5	It significantly reduces production and/or use of biogas.
High	4	It delays the development of biogas.
Moderate	3	It influences one part of the biogas value chain but does not have significant impact on the overall development of biogas.
Low	2	It has a limited impact on the development of biogas.
Negligible	1	It has virtually no effect on biogas production and/or use.

often referred to as the NIMBY ('not in my backyard') effect, is a significant concern for investors. Local residents sometimes oppose new biogas plants in their neighborhood due to concerns for expected negative impact due to smell or increasing transports, which may affect real estate prices [22,23]. Although this is not a risk that is directly related to policy, it can be considered a 'socio-political risk' as public acceptance and opinions can play a pivotal role in shaping government decisions [4].

Social concerns can generate demonstrations, which may bring negative attention and political or policy uncertainties [24,25]. In the biogas context, public acceptance affects permitting processes for new plants and localization patterns (P1). In Sweden, permitting processes for biogas projects may involve numerous authorities on different levels. The project's compliance with regulatory requirements and its impact on the community are evaluated, and there are many opportunities for different types of stakeholders to submit comments and complaints. Therefore, the 'NIMBY effect' (S1) often leads to delays. The participants saw this as a major risk for biogas projects in Sweden since such delays may dramatically impact time and cost for establishing new biogas facilities and jeopardize projects.

Both theoretical potential studies of biogas production and practical cost estimations are challenging, especially when combining them to provide guidance. Current potential studies face numerous limitations. For example, differences in methodologies lead to varying results, and potential future technological advancements are often overlooked [26]. Additionally, factors such as the scale of the biogas plant, equipment, realistic feedstock availability, transportation, processing, and labor costs must also be considered [27].

Deficiencies in certain strategies or policies

Long-term and predictable policies are necessary for a stable biogas market [3]. Some countries, such as Germany, Italy, the Czech Republic, and Denmark, have achieved rapid expansion of biogas production through fixed long-term incentives [3]. However, there is a 'lack of long-term strategies' (T1) for biogas development both at the EU and Swedish levels, which has led to unstable and unenforceable biogas development in Sweden. Achieving the EU goal of 35 bcm biomethane by 2030 [28] faces challenges without predictable support schemes. On the demand side, the upcoming 'ban on combustion engines in vehicles' (M1) exacerbates uncertainty surrounding future market demand for biogas among stakeholders in the Swedish biogas sector. The primary incentive for the Swedish biogas sector—the tax exemption—requires EU approval, as the EU Energy Taxation Directive [29] makes no difference between fossil and renewable energy sources.

Furthermore, the invalidation of the newly approved tax exemption from 2021 to 2030 by the General Court of the European Union has resulted in significant uncertainty for the entire Swedish biogas sector [30]. The European Commission has launched an additional investigation into whether Sweden's tax exemption schemes for non-food-based biogas led to overcompensation for producers selling biogas within the country [31]. This investigation allows Sweden to present its views. However, the prolonged waiting period continues to create uncertainty among biogas producers, consumers, and investors regarding investments in the sector, as they remain unclear about 'which sectors should or would utilize biogas' (M2).

The 'lack of clear standards for biofertilizer quality' (SUS1) poses a hindrance to realizing the benefits of this by-product of the biogas production. It has been shown that biofertilizers contribute significantly to enhancing nutrient uptake and improving soil health and, as a result, crop productivity increases and therefore it should be possible sell for a good price that would contribute to more profitable biogas facilities [32–34]. However, the establishment of standards for biofertilizer quality and facilities is lagging behind and this deficiency creates obstacles for an expanding biofertilizer market, especially in terms of exports [35]. This also makes biogas lose its competitive edge compared to other renewable energy sources.

Various limitations and limited system perspectives

On the supply side, whether there are enough available feedstocks for such levels of biomethane production is still uncertain [36]. The 'limitations of permitted feedstocks' (P2) are strongly connected to the Renewable Energy Directive (RED) [37], the Biodiversity Strategy [38], and the related Sustainability Criteria which regulate which feedstocks are permissible for advanced renewable fuels. The Sustainability criteria stipulate that feedstock cultivation must not lead to deforestation, land degradation, or the destruction of valuable habitats and the Biodiversity Strategy emphasizes minimizing the use of food and feed crops for energy production. These restrictions have already influenced the feedstock supply for biogas production, but it is uncertain how they will be interpreted and implemented in the future. The Swedish biogas sector does not rely on energy crops as feedstock, but it is critical to consider how the interpretation of the Sustainability Criteria is developing [20].

The legal safeguards regarding sustainable feedstock can increase the risk of 'competition over feedstocks' (P3) [36]. Such competition arises due to the limited availability of specific raw materials and lead to rising material costs, which could be linked to the risk of 'lack of policies for stable prices all over Sweden.' Biogas prices can vary based on different feedstocks, production capacities, locations,

Table 4. Identified policy risks for the Swedish biogas sector.

Risk category	Subgroup	Code	Risks	Type of policy	Adm. level	Adm. area	Value chain	Temporal change
Policy risk	Temporal risk	T1	Lack of long-term strategies	Regulatory	Overall	Overall	Overall	Uncertain
		T2	Swedish system lags behind the EU and global changes	Regulatory	National	Overall	Overall	Lagging
	Production risk	P1	Long and complicated permitting process	Regulatory	Local/national	Construction	Biogas production	No
		P2	Limitations of permitted feedstocks	Regulatory	EU	Agriculture	Feedstock supply, biogas production	Uncertain
		P3	Competition over feedstocks	Regulatory	EU/national	Agriculture	Feedstock supply, biogas production	No
	Market risk	M1	Ban on combustion engines in vehicles	Regulatory	EU/national	Transport	Biogas market	Changing
		M2	Lack of clear focus on which sector should use biogas	Regulatory	EU/national	Energy / transport	Biogas market	Uncertain
		M3	Lack of infrastructure and storage related policies	Regulatory	EU/national	Construction	Biogas production, biogas market and distribution, biofertilizer market	Uncertain
	Economic risk	E1	National subsidies conflict with the EU rules for overcompensation	Regulatory / Economic	EU/national	Economy	Biogas production, biogas market	No
		E2	Lack of policies for stable prices all over Sweden	Regulatory / Economic	National	Economy	Biogas production, biogas market	Uncertain
		E3	Difficulties for balancing theoretical production potential and practical costs	Regulatory / economic	National	Economy	Feedstock supply, biogas production	Uncertain
	Sustainability risk	SUS1	Lack of standards for biofertilizer's quality and facility	Regulatory	EU/national	Agriculture	Biofertilizer market	Uncertain
		SUS2	Lack of CO_2 utilization and storage policies	Regulatory	EU/national	Construction	CO_2 market	Uncertain
		SUS3	Limited system perspective – benefits of circular economy and sustainable food system	Regulatory	EU/national	Economy / agriculture / energy	Biogas production, biogas market and distribution, biofertilizer market	No
Social risk	Social risk	S1	Difficulties on local opposition – not in my backyard effect		Local		Biogas production	No

technologies, and more [39]. There are many different local and regional systems, price levels and fluctuations vary over the country, which could be a competition disadvantage for the biogas sector. The higher prices of biogas compared to natural gas or bioethanol, for example, indeed present an existing market barrier, increasing the risk for end-consumers to pay more than 'usual' [10].

'Limited system perspective—benefits of circular economy and sustainable food system' (SUS3) is another fundamental risk for the Swedish biogas sector since versatility is a representative characteristic of biogas systems. Failure to recognize the multifunctional features of biogas systems naturally increases risk such as 'lack of standards for biofertilizer's quality and facilities' (SUS1) and 'lack of CO_2 utilization and storage policies' (SUS2). The utilization of bio-CO_2 is valuable to enhance the circular value of the entire biogas system [40].

Regarding 'Swedish systems lagging behind the EU and global changes' (T2), it depends on which systems we are discussing. From a technological perspective, Swedish biogas systems, do not lag behind internationally. The Swedish biogas sector has historically utilized waste such as sewage sludge, manure, and other types of organic waste for producing biogas, rather than relying on any energy crops. The Nordic model of biogas solutions—primarily using urban waste for producing biogas and upgrading biogas for transport and using digestate as biofertilizer on farmland—contributes significantly to sustainable development goals [41,42]. However, Sweden lacks clear and long-term goals and stable support for production, especially in terms of realizing the large potential for increasing biogas production from the agricultural sector [19].

Different risks may also have the potential to interact with each other. A single risk can trigger subsequent risks, thereby creating a complex web of interconnected challenges. For instance, without clear and long-term incentives, the efficiency and profitability of the biogas sector will be impacted [43]. The absence of a national long-term strategy may also result in ineffective allocation of resources within the biogas sector, causing supply chain disruptions if abrupt changes in demand would occur. This may increase the pressure on available feedstock and result in dramatic price volatility. Therefore, it is crucial to pay close attention to these interconnections among risks when conducting a comprehensive risk assessment [44]. Furthermore, a unique characteristic of biogas solutions is the involvement and interconnections of many different administrative sectors. Overlooking these intersectoral connections may increase the risk of problem shifting [7]. While biogas, is generally recognized as a valuable renewable energy source, greater attention can be paid to the circular value of biogas solutions in the agricultural sector.

Risk evaluation

The distribution of respondents (Figure 6) shows a predominance of researchers and biogas company representatives (including producers, users, and distributors), with a smaller proportion from municipal and county representatives, as well as other biogas-related companies. This distribution provides valuable insights into the impact of policy risks on biogas. The preponderance of industry professionals suggests that the results primarily reflect their specialized knowledge and perspectives on how policy changes affect production efficiency, market access, and operational aspects of the biogas industry. The inclusion of responses from local government representatives offers a broader view of how these policies might influence local administration and implementation.

However, the overrepresentation of industry professionals may skew the findings toward industry-specific concerns, potentially underrepresenting the broader societal and environmental impacts of policy changes. Additionally, the relatively small number of local government representatives limits the understanding of policy effects at the

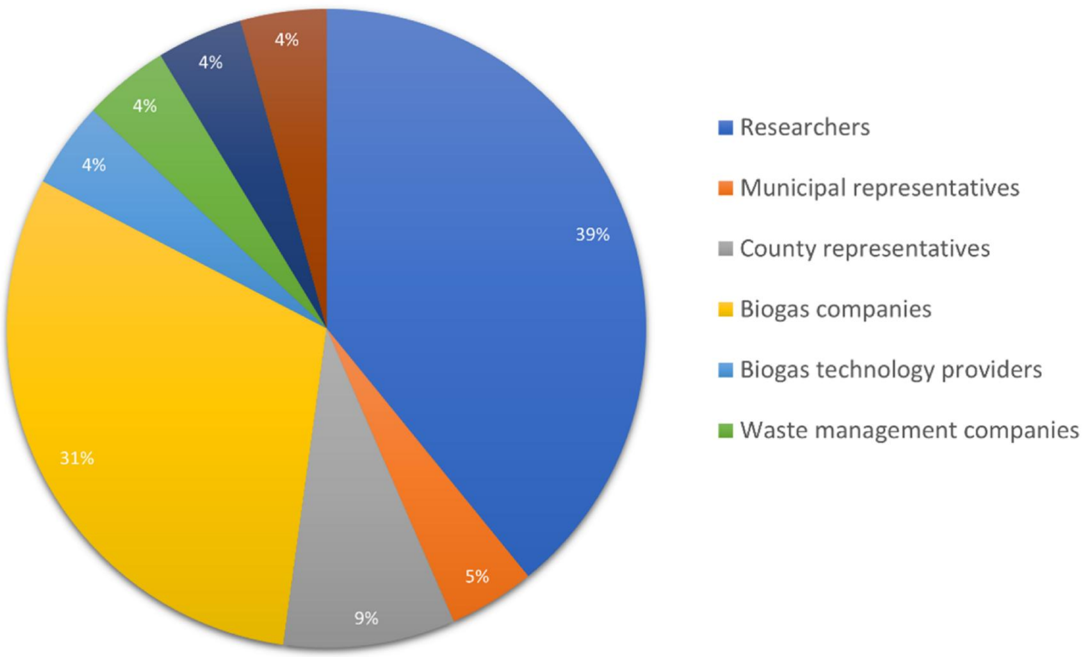

Figure 6. Distribution of respondents.

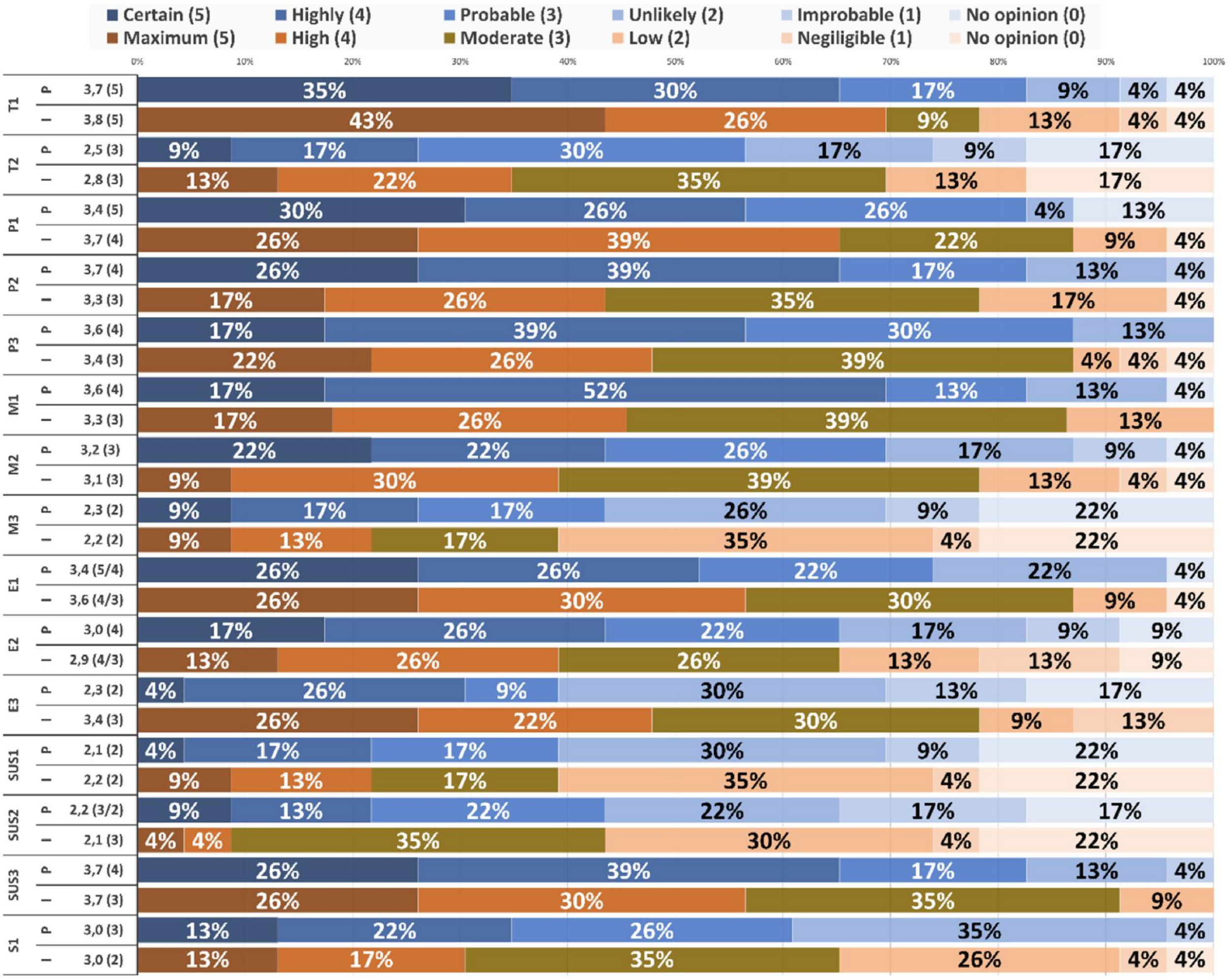

Figure 7. Probability and impact of policy-related risks. The letter 'P' stands for 'probability,' and 'I' stands for 'impact.' in the table on the left, the numbers on the left side represent the mean, and the numbers in parentheses represent the mode.

municipal and county levels. A more balanced respondent distribution would (likely) capture a wider range of perspectives and enhance the generalizability of the findings.

Figure 7 shows the results from the survey on probability and potential impact of the identified risks. In the left side, the mean and mode value of probability and impact of different risks are shown. In the right side, the distribution of respondents' evaluations of the probabilities (ranging from certain to improbable, including no opinion) and the potential impact (from maximum to negligible, including no opinion) of various risks on the biogas sector is illustrated. The mean values indicate that the risks that are deemed the most probable are 'lack of long-term strategies' (T1), 'limitations of permitted feedstocks' (P2) and 'limited system perspective—benefits of circular economy and sustainable food system' (SUS3), while the least probable risk is 'lack of standards for biofertilizer's quality and facility' (SUS1). The most impactful risk is 'lack of long-term strategies' (T1) and the least impactful risk is 'lack of CO_2 utilization and storage policies' (SUS2).

A considerable share of respondents finds the probability for the risk 'lack of a long-term strategy' (T1) and 'long and complicated permitting process' (P1) as 'certain', which means they are existing barriers for the Swedish biogas sector. 43% of the respondents are convinced that 'lack of long-term strategy' (T1) significantly reduces production and/or use of biogas, while 39% of the respondents think that 'long and complicated permitting process' (P1) delays the development of biogas. 26% of the respondents find the risk of 'lack of infrastructure and storage related policies' (M3) low and that this has limited impact on the biogas development. Even if limited number of gas filling stations is considered an important infrastructural barrier for biogas development internationally [10], this is not an issue in Sweden since 75% of produced biomethane used for road transport and there are numerous bio-CNG[3] filling stations and an increasing number of bio-LNG[4] filling stations [17]. Sweden is a pioneer in Europe regarding bio-CNG and bio-LNG development [17]. The limited gas pipeline infrastructure connected to the European gas network may pose a more important risk to the Swedish biogas sector especially since the EU promotes injection of biomethane into the gas network in the REPowerEU plan [45].

There is also a large share of respondents that 'lack of standards for biofertilizers' quality and facility' as unlikely risk to have much impact on the overall biogas development. The simplest and most valuable way to handle digestate—the remaining by-product of biogas production through anaerobic digestion—is to use it as biofertilizer. This minimizes negative environmental impacts and provide additional incomes to biogas producers [46]. Whether

Table 5. Strategies for risk mitigation.

Actors	EU	National	Local	Producer	Consumer
Strategies	Applying life cycle perspective		Fostering dialogue and trust among various stakeholders	Long-term agreements	
	Standardizing biofertilizer quality	Setting clear goals	Initiating permitting process earlier and working in parallel	Diversifying feedstocks and tailoring limitations on feedstock to specific countries	Diversifying energy portfolio
	Financing collaborative research between EU countries	Paying attention to potentials in agricultural sector	Communication and collaboration between different municipalities and regions	Communicating the circular value of biogas with farmers and users	Applying a holistic approach (e.g. LCA, MCA) for decision-making
	Both large-scale and small-scale biogas production	Paying attention to small-scale production to unlock potentials in rural areas	Prioritizing the value of existing infrastructure	Lobbying for extension of the gas network	
	Differentiating conditions for EU countries	Supports for large-scale production to achieve higher goals	Stimulating biofertilizer market	Plant-site selection	
	Incorporating global development into EU strategies	Searching for EU fundings			
		Coordination between EU and national level			
		Simplifying permitting processes			

it can be used as fertilizer in agriculture, depends on the feedstock used for the digestion process, as well as production and offset conditions [47]. In fact, there are regulations on the quality of fertilizers at the national as well as the EU level, i.e. Fertilizing Products Regulation [48] and the Animal by-products Regulation [49]. However, standardized testing measures and quality management systems for characterizing and commercializing digestate products are lacking [47]. Development of such systems may increase the use of digestate as fertilizer.

Risk mitigation

Based on the identification and evaluation of risks for the Swedish biogas sector, strategies for risk mitigation were identified and further elaborated. Table 5 presents a summary of formulated strategies.

The strategies are presented and discussed in the following order: the EU, the Swedish national government, local governments, biogas producers, and biogas consumers.

European Union

To mitigate policy risks at the EU level, multifaceted approaches were viewed as desirable by the workshop participants. First and foremost, participants claimed that adopting a comprehensive life cycle perspective throughout the policy processes is crucial. The EU has been considered a pioneer in integrating life cycle perspective into the development and application of policies [50]. Sala et al. [51] found that life cycle perspective was 'at the heart' in 60% of EU policies, including e.g. End-of-life vehicles EC 2000, Waste framework EC 2008, Eco-design EC 2009, Bioeconomy CEC 2012, and in 45% of communications. Recently, the European Green Deal stands out as a prominent example. Whether it is the Green Deal itself or other policies and strategies aligned with it, they have all incorporated life cycle concepts. In the food sector, the 'Farm to Fork strategy' [52] comprehensively addresses the origins of food, its nutritional value, and its environmental footprint. Similarly, in the fields of waste management, construction, and industry, life cycle assessment has been emphasized as a valuable tool for measuring both carbon footprints and resource consumption and promoting circular economy principles [53].

However, the EU faces the challenge of implementing life cycle assessment (LCA) and other life cycle concepts more thoroughly in policymaking. This involves the harmonization of a common knowledge base and life cycle methods adopted in various policy contexts [53]. For instance, the perspective on environmental impact of road transports is limited to the use phase and tailpipe emissions in EU policies (e.g. [54]. Electric vehicles are treated as having no emissions but from a broader life cycle perspective, their production and end-of-life phases, as well as the electricity system they rely on, they have important indirect emissions [55–58]. In contrast, biofuels generate CO_2 emissions during combustion but have an uptake of CO_2 in the early phases of their life cycle [56]. To consequently apply life cycle perspectives, participants emphasized that facilitating collaborative research initiatives among EU countries is essential, fostering knowledge sharing, and supporting innovation in biogas technologies.

Applying life cycle thinking can assist decision-makers in identifying trade-offs and synergies within the multiple functions of biogas solutions since it allows an examination of the contribution and combination of each constituent sub-process, facilitating a shift toward circularity in food and waste management [59]. The conversion of organic waste into biogas and biofertilizer closes nutrient loops [59,60]. For stimulating the development of the biofertilizer market, participants emphasized that it would be desirable that the EU standardized the quality of biofertilizers. This standardization is crucial for ensuring consistency and shaping a stable biofertilizer market, facilitating cross-border trade and promoting sustainable agriculture practices across the EU.

In terms of biogas production, participants suggested that the EU considers both large-scale and small-scale biogas production. Some participants even advocated for a prioritization of small-scale biogas production. Such an approach should, however, be supported by targeted incentives, active community engagement, and research into decentralized systems to effectively navigate the challenges posed by increased competition. While large-scale systems offer benefits in reducing costs and improving economic outcomes [61,62], decentralized systems, especially farm-scale biogas systems, play a crucial role in rural development and close the loop between agricultural waste, energy, nutrient recycling and reduce greenhouse gas emissions [61–64].

At the same time, participants stressed the necessity of acknowledging and adapting to the diverse conditions across EU countries to promote equitable conditions. These differences include varying feedstock availability, infrastructure conditions, primary markets for biogas and biomethane, technological progress, and support schemes. Meanwhile, incorporating global perspectives into EU strategies could help establish a common biomethane market and uphold principles of transparency and long-term planning. A common market may indeed stimulate the development of biomethane production. However, whether the volume of biomethane production could fulfill domestic on-site use or be fed into the natural gas grid to substitute natural gas remains uncertain [65]. Moreover, setting a common requirement for biomethane trading on the market is challenging because the conditions for biomethane production vary depending on feedstock availability, national incentives, regulations, and different greenhouse gas emissions reduction measures across different European countries [65].

National government

Participants found it desirable that the Swedish government develops long-term policies in alignment with goals set on the EU level and integrate life cycle concepts into policymaking. Long-term policies can create favorable conditions for the biogas sector and provide a secure environment for investments [3]. However, long-term policies must avoid being too technology-specific to prevent lock-in effects, particularly avoiding support schemes that may lock in the use of biogas to a specific application [3]. Therefore, long-term policies should ideally provide an overarching framework that allows for technological development. If life cycle thinking permeates the policy process it can prevent problem shifting [66] and ensure the inclusion of all values associated with biogas systems, including the value of digestate, bio-CO_2, and both the positive and negative environmental impacts of biogas systems [41,67].

Furthermore, participants highlighted that establishing a clear production goal is essential as it provides a starting point for subsequent actions. More attention should be dedicated to supporting biogas producers, particularly in harnessing their production potential within the agricultural sector. There exists an abundance of agricultural substrates and the benefits of nutrient circulation could be maximized [19]. This underscores the importance of prioritizing attention and support for small-scale biogas production to unlock the potential in rural areas. Simultaneously, recognizing the pivotal role of large-scale biogas actors is essential for achieving higher production goals. An integral step in securing financial support for various facets of the biogas sector involves exploring available funding opportunities within the EU. Effective coordination between the EU and national governments is crucial for implementing cohesive policies. For instance, participants highlighted that the long and complicated permitting processes pose a certain policy risk. Streamlining these permitting processes and standardizing procedures can help reduce administrative barriers, thereby facilitating the efficient implementation of projects. In this context, the EU is expected to provide overarching guidelines on how to expedite permitting processes [68]. Consequently, national-level authorities would be able to formulate specific procedures and requirements based on these guidelines.

Local government

For local governments, a key responsibility in mitigating policy risks is to play a role in fostering dialogue and trust among various stakeholders, aiming to alleviate the NIMBY effect [69]. Additionally, participants stressed that effective communication and collaboration between different municipalities and regions are crucial for shaping a common framework and market, facilitating the development of biogas across sectors. The cooperation between different sectors and actors is often challenging due to a lack of shared information and trust. Local authorities, given their proximity and community ties, are well-positioned to act as intermediaries to establish platforms based on trust. For example, the municipal organization can serve as a bridge facilitating activities among local feedstock suppliers, biogas companies, and consumers of biogas and its by-products [70]. Finally, local authorities should carefully consider how to prioritize the value of existing infrastructures to develop the biogas market. They also need strategies for stimulating the biofertilizer market. The potential utilization of biofertilizer does not align with its current production potential. The potential market for biofertilizer can be extended beyond agricultural land to include areas such as forests, municipal parks, and private gardens [70]. Municipalities can be essential actors to facilitate the coordination between production and demand of biofertilizer [70]. This comprehensive approach involves assessing existing infrastructure, aligning strategies, and fostering collaboration among stakeholders.

Biogas producers

For biogas producers, the lengthy and intricate permitting processes are the most important policy risk. To mitigate this risk, participants recommended initiating the process earlier and working concurrently with various permitting authorities. Engaging in face-to-face meetings to discuss and expedite the process was also proposed. For companies expanding to other countries, participants suggested tailoring limitations on substrates to the specific countries. This is crucial because the use of crops for biogas production varies between nations. It is necessary to align technology with the characteristics of the target market to enhance generic export promotion initiatives and increase their effectiveness [71]. Participants suggested that educating farmers and users on the circular value and multiple benefits of biogas can foster understanding and cooperation. This may encourage farmers and users to sign long-term agreements with producers. Furthermore, diversifying products and customers, including strengthening the biofertilizer and bio-CO_2 markets, is equally important. Participants also suggested that large gas companies should be expected to lobby for the extension of gas networks to connect to European natural gas grid. Site selection plays a central role for mitigating various risks for producers, including local opposition, expediting the permitting process, ensuring feedstock availability, and facilitating the development of necessary facilities and infrastructure [72,73].

Biogas consumers

Drawing upon lessons from producers, biogas consumers can mitigate policy risks by adopting similar approaches while recognizing their position in the biogas supply chain. Especially for industrial consumers, participants pointed out that establishing long-term agreements becomes crucial in securing a stable and predictable biogas supply. By securing commitments from suppliers, consumers can effectively navigate risks associated with policy changes that might impact short-term availability or pricing. Another strategic move involves actively diversifying the energy portfolio, incorporating biogas as one of two or more options. This diversification emerges as a robust risk mitigation strategy, especially in situations involving risks for supply shortages or price volatility [74]. Providing flexibility in energy sources ensures that consumers can smoothly adapt to changes in policy dynamics without encountering disruptions.

Furthermore, a holistic approach, based on multi-criteria analysis, life-cycle perspective, and systems thinking, is recommended for decision-making [75,76]. Even though such an approach may not directly diminish risks for consumers, a comprehensive understanding allows stakeholders to grasp the intricate dynamics of the biogas market, identifying potential challenges and opportunities across the entire supply chain. By assessing the broader system effects, stakeholders can identify and mitigate risks before they escalate, contributing to a stable market environment. Holistic approaches prioritize sustainability considerations, aligning the market with broader societal goals and enhancing resilience against fluctuations in public perception and regulatory changes.

Conclusion

This study aimed to identify and evaluate policy risks associated with the Swedish biogas sector and formulate strategies to mitigate them. The findings indicate that 'lack of long-term strategies' represents the most significant policy risk for the Swedish biogas sector, both in terms of probability and impact. The 'lack of long-term strategies' and 'long and complicated permitting processes' are existing and significant barriers for the biogas development in Sweden. A lack of a clear and predictable policy framework for the biogas sector can cause hesitation among producers, consumers, and investors, and potentially lead to investment reluctance and financial losses (e.g. revocation of tax exemptions and retroactive payment). Additionally, long and complex permitting processes can delay biogas projects, resulting in postponed returns. For the Swedish biogas sector, EU's increased focus on biogas seems hopeful since it may elevate biogas to a new stage of development but simultaneously it introduces risks in terms of policy changes and uncertainties. If there is a lack of understanding of the multiple benefits of biogas systems, it may result in policies that do not support the circular value of biogas. A thorough understanding of the system's multifaceted dynamics is furthermore essential for enabling accurate evaluation of potential vulnerabilities and the development of effective risk mitigation strategies. Social uncertainties appear to be one important type of risk for the Swedish biogas sector. Therefore, a broader socio-political perspective, rather than only a policy or regulatory perspective, would be desirable.

If the EU consistently recognize the circular value of biogas solutions and adopt a life cycle perspective for decision-making many of the risks experienced by the Swedish biogas sector would be mitigated. To some extent, the EU should harmonize production standards to help shape a common market. However, the EU must also balance harmonization with the varying conditions in member states, which may present a challenge. If the EU keeps pace with global developments, it will help establish a common biomethane market to promote the overall development of the biogas sector.

The Swedish government should set a clear production goal and establish a long-term strategy for the biogas sector. The introduction of effective mechanisms to explore funding opportunities at the EU level can also be beneficial. In the case of the permitting procedure, both the EU and national governments should establish clear requirements for biogas plants and simplify the complexity of administrative procedures. It would also be desirable that the Swedish biogas sector pay more attention to the agricultural sector, both for the production and utilization of biogas and its by-products.

Local governments are expected to facilitate coordination among communities, various stakeholders, and municipalities. For biogas producers and consumers, strategies to mitigate policy risks are quite similar, emphasizing the importance of securing long-term agreements and diversifying options. The key difference is that biogas producers may play a more significant role in lobbying for streamlined permitting processes and improved infrastructure, while consumers may focus more on understanding the dynamics of the biogas market, thereby adopting a holistic approach to decision-making.

As a follow-up to this study, there is a need for future research to focus more on specific administrative levels, such as the EU, regional, or local levels, to investigate the specific influences of policies and, accordingly, provide policy recommendations. Furthermore, it would be desirable with assessments of how policies at different levels influence the biogas sector based on both quantitative data (e.g. biogas production metrics, policy impact indicators) and qualitative data (e.g. interviews with policymakers, case studies). Additionally, future research should investigate other countries and evaluate policy risks from a broader socio-political perspective and compare these across different contexts.

The same approaches used in this study could be applied, but to facilitate cross-country comparisons there is a need to develop a common set of indicators for evaluating policy risks. By comparing the identified risks and socio-political factors across countries, it could be better understood how different contexts influence the biogas sector.

Notes

1. Approximately 95% of the imported biogas comes from Denmark [16]. In Denmark, the support systems are aimed at production, whereas in Sweden, the support systems target the usage side.
2. Bio-CO_2 refers to biogenic carbon dioxide that is separated from the gas flow during the biogas upgrading process, resulting in a high-energy content gas, namely biomethane.
3. Bio-CNG refers to biological compressed natural gas, which is essentially compressed biomethane derived from organic waste.
4. Bio-LNG refers to biological liquified natural gas, which is essentially liquified biomethane derived from organic waste.

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