Understanding failure to adopt biogas: Application of the system failure framework in the Biogas industry of Greece

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Executive Summary

The European Union has established specific goals to promote the use of biogas as part of a broad strategy to transition to sustainable and renewable energy systems. Biogas, derived from the anaerobic digestion of agricultural, livestock, and other organic feedstocks plays a pivotal role in reducing greenhouse gas emissions and contributing to the EU's energy transition objectives. Despite its significant potential, Greece remains behind other EU countries in biogas production.

This study aims to identify the systemic barriers preventing the growth of the Greek Biogas Innovation System (GBIS).

The primary research question thus focuses on a clear identification of the system barriers in the Greek Biogas Innovation System. Additionally, to realize this study other research sub-questions focus on initially identifying the characteristics of the Greek Biogas Innovation System, moving to distinguishing the system failures occurring in the system, and finally identifying and addressing the challenges of community inclusion in the GBIS. Through the analysis of this study's findings, this research also proposed certain recommendations related to the detected systemic barriers.

The methodology is based on a qualitative case study approach focusing on the region of Thessaly, which was selected based on its significant biogas industry and recent flooding events that weakened its communities. The data collected was derived from constructed semi-structured interviews with various stakeholders, including biogas producers, biomass suppliers, research organizations, energy communities, funding organizations, natural gas experts, biogas entrepreneurs, and community members.

The theoretical foundations of this study are based on the Technological Innovation System approach and the application of this approach to the System Failure framework which is employed to identify broader systemic issues that hinder the development and performance of innovation systems. Additionally, the study incorporates stakeholder participation and participatory design to ensure the perspectives of all involved parties, directly and indirectly related to the technology are considered.

The findings of this study characterize the GBIS as a diverse network of stakeholders, including biogas companies biomass suppliers, municipal and governmental bodies, financial and research organizations, and biogas associations under the context of international, national, and regional levels. Additionally, the relations between the stakeholders are identified including positive, negative, weak, competitive, and advocatory relations between them. Key functions such as entrepreneurial activities, knowledge development and diffusion, market formation, and resource mobilization are present but not fully optimized.

The system exhibits infrastructural failures related to the outdated electricity grid and institutional failures related to complex bureaucratic processes, regulatory gaps, and inefficient waste management regulation compliance. Interaction failures relate to strong and closed networks hindering collaborations and information exchange, and capability failures occur as

the system lacks the organizational capabilities to overcome obstacles such as unstable feedstock supply leading to problems with the availability of resources. Certain market failures such as the market price of biomass and the absence of big players are also related to existing systemic barriers. Additionally, problematic media portrayal, local opposition due to environmental concerns, and odor issues, coupled with misinformation about biogas technology limit public acceptance and community involvement resulting in community-related barriers. Finally, unexpected events such as climatic risk due to natural disasters were identified as an issue not being categorized under the usually studied systemic failures. This issue highlights the multiple impacts of such events on the technology and the local communities with the system design itself not being prepared to withstand extreme phenomenons that eventually magnify the other existing systemic problems.

Community engagement is vital for the successful adoption of biogas technology, however, challenges such as negative perceptions of biogas plants, lack of information on biogas technology, and no observed benefits discard communities from actively participating in the system.

This research focused on providing recommendations to address the identified barriers in order to support production, address institutional barriers, and enhance community engagement. For assisting production, public investments in upgrading the electricity grid are essential for new permits while centralizing biomass gathering through third parties or collaborations between municipalities and biomass suppliers can stabilize feedstock supply. Strengthening cooperation between stakeholders, facilitated by the Hellenic Biogas Association and academia, is crucial for joint R&D projects while developing educational tools and training programs by universities and biogas companies can create skilled workforce.

Institutional reforms are necessary to address regulatory bottlenecks with recommendations targeting the need for biomethane regulations with incentives for production and detailed technical standards. Additionally simplifying bureaucratic processes, closing regulatory gaps, and providing incentives for stakeholders to comply with environmental regulations will enhance feedstock availability and eliminate administrative obstacles. A central organizational body for GBIS can streamline administrative procedures, and improve resource management and information diffusion for new entrants to enter the industry.

Biogas Companies should address community needs before starting new projects to ensure local acceptance while strengthening energy communities at a regional level can help locals produce their own energy through autonomous schemes and educate them on the benefits of biogas technology. Promoting public awareness and acceptance through media and local municipalities, and involving communities in biogas projects, can enhance public perception and acceptance.

In conclusion, this study aimed to address the systemic barriers of the Greek Biogas Innovation System in order to increase the production of biogas and engage local communities in involvement and acceptance of the technology. As several recommendations were able to be proposed, the utilization of the TIS approach and the integration of the System Failure framework with stakeholder participation and participatory design approaches, provided a comprehensive method to analyze the existing problem and assisted in identifying systemic barriers located across the whole value chain.

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1 Introduction

1.1 Research Introduction

The European Union (EU) has established specific goals to promote the use of biogas and boost its production as part of comprehensive strategies that aim to advance the energy transition to more sustainable and renewable energy systems.

Energy produced from agricultural, organic, and forestry feedstock is considered one of the main renewable sources of energy in the European Union as it constituted around 59% of renewable energy consumption in 2021 (European Commission, 2023b). This is highly linked with the efforts to reduce greenhouse gas (GHG) emissions and maintain the global average temperature rise below 2 degrees Celsius based on the Paris Agreement (United Nations Climate Change, 2015). As such, the EU's initiatives to grow biogas production directly adhere to these established goals in support of the energy transition.

Biogas, the product of anaerobic digestion of biomass (Wilkinson, 2011) is regarded as a promising solution that can reduce Green House Gas emissions and as an energy-rich product it can have an effect on the emissions from the agricultural, waste management, and industrial sector (Nevzorova & Karakaya, 2020).

Among the European countries, Germany is the leading producer of biogas with 8.35 bcm (billion cubic meters) of biogas production in 2021. On the same page, Italy (2.3bcm), France (1.6bcm), Austria (0.21), Sweden (0.2), and the Czech Republic (0.7 bcm) are also considered as mature in the biogas technology market and have multiple drivers that have accelerated their transition to this technology (European Commission, 2023a). These mechanisms are according to Nevzorova & Karakaya, (2020), related to the country's "proaction to challenges, policy support, cooperation, and capability of technology".

Greece as a biogas producer lies far from the matured countries mentioned, with a production of 0.1 bcm in 2021 which equals to 2.3% of its natural gas supplies (European Commission, 2023a). However, there is large potential for the country to such a degree that it would be possible to achieve 39% of its energy needs by utilizing the potential of its agricultural and livestock manure residues (Vlyssides et al., 2015).

This implies that a large amount of the country's capability is currently not being used, as the majority of agricultural and biomass residues are being burned or disposed of uncontrollably in fields (Aravani et al., 2022). The described situation raises the importance of accelerating the adoption of biogas technologies in Greece but at the same time highlights the importance of first understanding the barriers to adoption that exist in the country.

1.1.1 A need to identify the barriers to biogas adoption

Advancing to a wider level by analyzing a large number of countries, Nevzorova & Kutcherov, (2019) indicated that the barriers to the wider implementation of biogas are mainly technical, economic, market, institutional, socio-cultural, and environmental. Furthermore, the researchers further indicated the importance of the involvement of various stakeholders including the private sector, governments, financial institutions, R&D institutions, lobby groups, media, and local communities to address these issues.

The stakeholder involvement aligns with Wüstenhagen et al., (2007), who point out the factor of social acceptance as one of the barriers to succeeding in implementing renewable energy projects. Related to the issue of social acceptance the authors also point out the community acceptance of renewable energy projects and its relation with distributional justice, procedural justice, and trust in the project actors.

These findings highlight the wider issue of the adoption of biogas as a renewable source of energy and the wide range of these barriers stresses the importance of a more detailed analysis of the country-specific issues that slow down the adoption process. At the same time, barriers related to the acceptance of the technology by locals and their involvement in these projects are also important to be further addressed.

1.1.2 Analysis on a TIS level

For realizing such an analysis, the System Failure Framework provides a basis upon which the biogas technology in Greece can be evaluated. This framework provides practical guidelines and grounds for policymakers, enabling the distinction between different forms of system flaws and the actors that should address them (Klein Woolthuis et al., 2005). By adopting this theoretical framework, which is focused on Innovation Systems evaluation, biogas technology is understood as a "sociotechnical system" based on the need for a combination of institutional and technological knowledge. As a result, it can be analyzed as an innovation system and more especially the Technological Innovation System (TIS) (Borges et al., 2023). Through understanding the biogas technology as an innovation system, it is possible to then apply the systems failure framework for the purpose of this Master Thesis and evaluate the existing imperfections in the Greek Biogas Innovation System (GBIS).

1.1.3 The role of stakeholder and community engagement

As it has been understood the role of community engagement and acceptance is a crucial characteristic of renewable energy adoption. Involving community representatives and end users as active participants in technology innovation can effectively boost the social acceptance of renewable energy technologies (Wüstenhagen et al., 2007).

The growing importance of engaging communities to participate in the production of renewable energy is additionally an emerging solution, with the number of active communities in countries such as Germany and the Netherlands having a strong established number of groups that cooperate and contribute with their own energy production. Existing reasons for many communities to actively participate in energy production can be financial, environmental, or even related to the need for energy security (Dóci & Vasileiadou, 2015).

As it can be understood the role of community engagement can take various forms that can benefit renewable energy adoption, especially for a source such as biogas. Communities, as seen above, can be a driving force for technology acceptance and development in a region while can also take action and have a direct contribution to the technology diffusion and implementation.

Thus, in the context of this study, taking into account the diverse and important role of communities and locals can broaden the analysis and help draw results on understanding the system failures of the Greek Biogas Innovation System (GBIS) and the needed system changes that address a wide range of directly and indirectly involved stakeholders.

To achieve the integration of community participation into the system failure framework the approaches of stakeholder participation and the democratic basis of participatory design (PD) are utilized in this study. Such approaches as stakeholder participation and in this case, community participation in the GBIS, can assist in improving the quality of environmental decisions based on trust, empowerment, equity, and learning (Reed, 2008). In addition, the PD basis can establish the need to address the requests of indirectly related stakeholders such as communities that are affected by the technology, strengthening the need to provide a responsible process for taking such stakeholders into account and addressing their requirements (Ten Holter, 2022).

1.1.4 Case Study: Thessaly Communities and Recent Floods

The recent catastrophic floods of September 2023 due to the heavy rainfall caused by a low-pressure storm in Thessaly (Nasa Earth Observatory, 2023) known also as “Daniel Storm” has devastated the agricultural and livestock farming industry of the region while also destroying houses and infrastructure in local communities (Clea Skopeliti, 2023).

This devastating natural disaster highlights the urgent need for sustainable energy solutions in support of the region. As Thessaly has an existing biogas industry, the region provides an ideal case in order to examine the existence of the Greek Biogas Innovation System, its characteristics, system failures, and needed system changes. Additionally, it is also possible to examine the effects of the natural disaster in the area and the needs of the local communities. Sych an analysis can reveal the needed system changes that could serve as a basis for actively including the region’s communities in biogas technology and the locals' further acceptance of the technology.

Based on this logic, to understand the existing system failures in the Greek Biogas Innovation System, a case study approach will be used in the region of Thessaly in Central Greece and multiple data collection methods will be used including semi-structured interviews with biogas stakeholders and community members in the area. These interviews will be focused on providing an understanding of the existing Greek Biogas Innovation System, the problems that the directly involved actors face along with the needed changes for a robust system while the perspectives for community engagement will be taken into account for the design of a more inclusive environment around biogas technology.

1.2 Problem Statement and Research Questions

A specific approach that could shed light on the existing issues of the Greek biogas adoption on a local level could help realize the factors that act as barriers to the further expansion of Biogas Technology and discourage directly involved stakeholders or the local communities from implementing drastic changes to the existing biogas innovation system. Additionally, this analysis focusing on the regional characteristics of biogas can help draw results on a national level and produce generalizable findings that represent the entire Greek Biogas Innovation System.

Realizing this research will provide an understanding on the dynamics of the biogas innovation system in Greece the existing barriers and the challenges and opportunities for wider inclusion. Based on the above information the question that needs to be answered for this Master Thesis is:

"What systemic barriers are preventing the growth of the Greek Biogas Innovation System?"

From this main question, further sub-questions arise to provide answers to the posed inquiry:

- What are the characteristics of the Greek Biogas Innovation System?
- What are the system failures related to the biogas adoption in Greece based on stakeholders directly and indirectly related to the biogas innovation system?
- What are the challenges of community inclusion in the Greek Biogas Innovation System and how can these issues be surpassed to address the community needs through engagement?

These sub-questions serve to further understand the nature of the biogas innovation system and the barriers observed in the Greek biogas environment. By identifying the characteristics of the Greek Biogas Innovation System it is possible to map the existing stakeholders and build an understanding of the existing relations and system functions.

Subsequently, the analysis of the existing challenges observed, can highlight the system imperfections hindering the biogas expansion in the area and lead to clear changes that will support the technology development. The last question moves the analysis toward understanding the issues related to community engagement in the context of biogas technology and the ways these challenges can be tackled.

1.3 Organization of the Thesis

This section explains the structure of the following chapters of this Master Thesis and provides a rationale behind this chosen organization. This Thesis is organized into seven chapters, including the Introduction, each focusing on a specific aspect of the research conducted.

In the next chapter the Theoretical background, the theory used for this study is presented highlighting the importance of biogas technology, key theoretical aspects used in this Master Thesis, and previous research findings related to the topic. This chapter links each theoretical element to provide a clear understanding of the frameworks used and their significance. By integrating the theoretical aspects and related literature findings, this chapter offers a comprehensive understanding of the theoretical foundations relevant to the study and their application in previous research related to biogas technology.

The The case of Biogas in Greece chapter introduces specific information regarding the presence of biogas in Greece and aims to focus on the existing problem of biogas adoption in the country. It focuses on the existing problem of biogas adoption, barriers to the technology in Greece, and the inclusion of communities in the technology. This chapter provides a detailed introduction to the case of Greece and links the theoretical background with the country-specific analysis that is realized in this Master Thesis.

The Methodology chapter describes the research methodology, including research design, data collection methods, and data analysis techniques providing a detailed overview of all the actions taken in order to realize this study.

The Results chapter presents the results of the study, while the Discussion chapter analyzes these results in the context of the existing literature, and theoretical frameworks, addressing the research questions, highlighting this study's contributions, and providing recommendations.

In the final chapter, Conclusions, the thesis is concluded by summarizing the main findings and providing recommendations for future research.

This structuring allows this thesis to dive deep into each aspect of this research and methodically target the research objectives. Due to the complexity of the topic, the various stakeholders, and the multidisciplinary nature of the biogas industry, this study aims to provide comprehensive information on each element while the chapters complement each other linearly. This approach ensures that the reader can follow the research process without missing any crucial information, making it possible to analyze this complex issue thoroughly. This organization was chosen to provide a logical and integrated flow of information, aligning all the aspects of this study in order to ensure a coherent narrative through the thesis.

2 Theoretical background

To set up the basis for this study it is first important to understand certain theoretical elements that will help answer the research questions set in Introduction. These elements will establish the foundations of this research and focus on existing literature and information related to the objective of this study.

Initially, the importance of biogas as an energy source will be supported in Importance of Biogas as an Energy Source part, followed by information on its current adoption in Europe and EU targets in Current adoption in Europe and key drivers part. To analyze the biogas technology system the theoretical foundation of Innovation Systems and Technological Innovation Systems will be presented in Innovation Systems (IS) followed by existing literature on Biogas TIS in Biogas Innovation Systems: Country Examples. The introduction of the theory behind the System Failure Framework will support the analysis of the systemic barriers to be examined in the Greek Biogas Innovation System in System Failure Framework and finally, the Stakeholder Participation & Participatory Design will highlight the importance of incorporating the perspectives of various stakeholders in an effort to understand the systemic barriers.

2.1 Importance of Biogas as an Energy Source

To initially understand why it is important for European countries and the European Commission to set strong targets for biogas adoption and production it is first important to realize this technology's potential and the problems that it solves.

In this part, the characteristics of biogas will be presented to form an understanding of how this technology and its products can help foster energy transition and benefit the European Countries.

2.1.1 Why Biogas?

The importance of renewable energy sources will play a crucial role in achieving carbon neutrality by 2050 and as a result, renewable gases are valuable in accelerating energy transition in the European Union. Biogas and biomethane (its purified product) can prevent emissions across the whole value chain. These include the natural emissions from the decomposition of organic matter and wastes, the fossil fuel emissions from replacing fossil fuel energy sources, and finally the carbon emissions from fertilizer production as the digestate byproduct of biogas production can be used as a biofertilizer (European Biogas Association, 2020).

These advantages directly highlight the importance of adopting biogas to a wider extent by European countries. Moreover, other problems that require drastic solutions can be directly addressed through the adoption of this technology in the European environment.

The ongoing energy crises, fossil fuel depletion, high costs, and environmental issues require drastic shifts to renewable energy sources (Mignogna et al., 2023). Recent events, such as the Ukraine war, have underscored the issue of national self-sufficiency in energy supply for certain countries and the greater energy dependence on foreign countries requires urgent actions in the waste and biomass utilization to produce valuable competitive materials and energy (D'adamo & Sassanelli, 2022).

2.1.2 Characteristics of Biogas Technology

In more technical terms, biogas is comprised of methane in its majority and contains around 30-40% of carbon dioxide. It can be produced in numerous ways and from a great variety of organic substances. Focusing on anaerobic digestion, biogas production comes from organic waste processing with the addition of anaerobic bacteria (Markard et al., 2009). Biogas can be produced from various sources of agricultural, municipal, or industrial origin. The most common forms of waste that are used for energy production include agricultural waste, municipal sewage sludge, wood waste, energy crops, animal manure, algae feedstock, dairy waste, and dairy wastewater treatment plant sludge. These feedstocks can be applied in anaerobic co-digestion for the purpose of biogas production, and this results in the use of various combinations and proportions to achieve optimization in a biogas plant (Ignatowicz et al., 2023).

In addition, Mignogna et al., (2023) highlights the efficiency of the process of Anaerobic Digestion (AD) in biogas production from waste of different origins and the excellent way co-digestion of feedstocks improves biogas production. This helps further realize the high technology readiness level which is at Technology Readiness Level (TRL):9 (Joint Research Centre, 2022).

This high technological maturity can also be understood from the various ways biogas can be used at a later stage. Biogas plants operate by generating power and heat in a co-generation unit (Combined Heat and Power, CHP) with electricity typically supplied to the grid and heat being locally utilized during the continuous digestion process. Considering the low efficiency of the above process (60%) it is also possible to refine the produced gas through desulphurization, dehydration, and CO2 separation for a final product with more than 96% methane concentration. This product also known as biomethane, allows biogas to be used as a fuel for cars and other vehicles of power production (Markard et al., 2009).

What can be realized from the above information is that biogas technology provides the solutions and is in such a technological stage that it is beneficial for countries to adopt it. This highlights the importance of understanding the existing barriers in a system in order to help the technology be more widely applied.

2.2 Current adoption in Europe and key drivers

After presenting the characteristics of Biogas Technology and its importance as a solution in energy transition, it would be valuable to highlight the current status in Europe and successful cases related to biogas. This can provide important points for the analysis of the existent biogas industry of Greece and will serve to understand what factors contribute positively to the adoption and diffusion of the technology in successful cases.

2.2.1 EU targets and technology adoption growth

The European Union (EU) has set certain targets in order to spread the use of biogas and increase production under broad strategies to foster energy transition to more sustainable and renewable energy systems.

The Renewable Energy Directive (RED II) is a target under which the EU has instructed that at least 32% of its energy consumption must come from renewable sources by 2030 with biogas produced from organic materials such as agricultural residues, manure, and other organic wastes being a key component of these sources (European Commission, 2018). As part of the European Green Deal, the European Commission has constructed a strategy to reduce methane emissions by 2030 contributing to the Commission's zero-pollution ambition. Under this strategy, biogas is shown as a way for energy production and methane emissions reduction in rural areas under the utilization of organic wastes (European Commission, 2020).

In addition, the Circular Economy Action Plan under the Biodegradable Waste Plan promotes the use and production of biogas to achieve a more sustainable circular economy (European Commission, 2020). Under the National Energy and Climate Plans (NECPs), member states are required to develop and implement NECPs outlining their strategies to meet EU targets and utilize the potential of biogas and biomethane. Each country must submit a progress report every 2 years with a horizon to meet the targets until 2030 (European Commission, 2019). These plans are linked with the existing previous National Renewable Energy Action Plans (NREAPs) laying out how member states would achieve their binding renewable targets across different energy sectors. Until 2020, 10 Member States were expecting to achieve a total surplus of around 2% in total renewable energy (Capodaglio et al., 2016).

Finally, the Horizon Europe program is focused on funding research and innovation until 2027 with a budget of 95.5 billion euros in order to reinforce the EU's scientific and technological bases, increase its innovation output, and create an impact on the existing European Green Deal strategy. These initiatives are centered around improving the efficiency of technologies such as biogas to boost bioeconomy (European Commission, 2021).

2.2.2 Current Adoption of Biogas

Following the existing targets and strong focus on aiding the biogas technology, Europe is currently a world leader in biogas production with significant progress being made in the sector as more than 17,000 commercial biogas plants were already established by 2018. In several countries, the biogas market development has been favored by positive policy framework conditions, programmes, and financial support. (Scarlat et al., 2018). Industrial-scale biogas plants have been built in Western Europe since the 1980s but the EU countries' commitments in accordance with the need for greenhouse gas emissions reduction have resulted in the increase that has been observed in recent years (Ignatowicz et al., 2023).

Understanding the growth patterns, it can be observed that Europe has seen rapid growth in the sector from 2009 to 2014 with more than 10,500 plans in total, and a steadier growth from 2014 to 2019 with more than 1,900 plants in total (European Biogas Association, 2020). Certain country examples are presented below in order to strengthen the points made above.

2.2.2.1 Germany

Germany is the market leader both in biogas technology and also as a biogas producer contributing to more than half of the total European biogas energy production (Pazera et al., 2015). The country's biogas market is directly linked to the implemented support schemes and feed-in-tariffs (FiT). The feed-in tariff policy from the Renewable Energy Sources Act (EEG) directly created the market in 2004 for technological biogas solutions providing incentives and attractive bonuses for the digestion of plant material (Nevzorova & Karakaya, 2020). The 2004 law had such an effect that 600-800 plants were constructed between 2005 and 2006 with the FiT also having an effect of a 5% contribution on the energy prices (Wilkinson, 2011).

Examining the advancement in cooperation, the existing established national innovation network (German Biogas Association) and the many innovative projects in the country showcase the successful network creation and the cooperation characteristics that additionally contribute to the success of the system. Moreover, while contributing to biogas production the country is also an important service and knowledge supplier with numerous German projects providing services and support in different European biogas projects assisting in knowledge sharing and technology diffusion. The existing strong market and growth slowed down after the 2012 amendment of the EEG as the FiTs were reduced (Nevzorova & Karakaya, 2020; Torrijos, 2016).

The current discussions in the country, affected by the demand and reduced subsidies, are mainly centered around the improvement of biogas plants in terms of economic efficiency using cost-effective substrates, improving energy efficiency, and flexible power production (Winquist et al., 2021).

Overall, in the case of Germany, specific factors that influenced the success of biogas adoption especially for on-farm plants were related to a variety of environmental, energy security, farming, and economic factors. Some of them are the European environmental targets and reduction in emissions, the existing high energy imports, with more than three-quarters of natural gas imported from Russia, the need for manure management, the soft loans and capital investments grants, and the FiT bonuses for using specific substrates for the anaerobic production (Wilkinson, 2011).

2.2.2.2 Sweden, Austria and Poland

In Sweden, another leading biogas market investment programs promote biogas production, and in Austria, the investment programs were able to increase the efficiency of biogas plants by up to 60% (Nevzorova & Karakaya, 2020). Based on the number of plants various countries show high levels of adoption with Germany (10,000 plants in 2020) and Poland which from 45 agricultural-only plants in 2014 climbed to 128 in 2021, being characteristic examples of the growing sector (Ignatowicz et al., 2023).

2.2.2.3 Denmark

Another country example in Europe that could be regarded as a successful case is Denmark. Accelerating in the periods of 1990s and 1980s, the biogas industry in Denmark succeeded in important development in the industry through a centralized biogas plant concept that emerged from the Biogas Action Programme. Through the development of social networks that supported the centralized biogas plants, the Danish government achieved the participation of many different actors. At the same time, the technology was supported with action programmes and financial aid while the Danish farmers created cooperations in the form of small communities that eventually benefited the centralized biogas plant development (Raven & Gregersen, 2007).

2.2.2.4 Italy, UK and France

In Italy, the UK, and France the total production constituted in 2014 amounted to 31.8% of the total Europe production. Mainly dependent on biogas production from landfills, Italy and France made efforts to adopt the anaerobic digestion of also other substrates (Maroneze et al., 2014). In the case of Italy, the country numbered around 1391 biogas plants by 2016 and the biogas market relied upon the FiT policy. The result of this action helped large plants be developed at a high pace up to 2011 with energy crops as the main type of substrate (Torrijos, 2016). Biomethane production has been benefited through cooperative actions such as big companies' innovations (biomethane injection in natural gas grid and methane distribution plants by Fiat Chrysler Automobiles Group) or farmer cooperatives (agro-energy plant development by 14 farmers) (Nevzorova & Karakaya, 2020).

According to the European Commission, (2023a) with a production of 1.6 bcm in biogases France is one of the EU27 countries with the fastest-growing biomethane market. Energy Transition for Green Growth Law and Long-Term Energy Schedule (PPE) have set goals to reach a 10% contribution of renewable gases in the natural gas network by 2030 and by 2022 the country had 1705 biogas production units (Terėga, 2022).

As can be observed through the many different cases of European Countries in the biogas sector, the successful development is highly linked to different drivers for adoption that, based on Nevzorova & Karakaya, (2020) can be understood under the TIS approach. As a result, these drivers are related to the countries' responses to challenges such as energy security, climate change, and waste management. Furthermore, it is also observed that institutional provision, as the paradigms showcased above, represents much of the support for the technology diffusion, while the different networks and partnerships created, play a key role in collaboration and knowledge development. Finally, the technological strength as a driver emerges after examining the suitability of the technology in the different needs and existing environments in each case.

What can be understood in this part is that certain EU countries have moved into following the targets set and realizing the potential of biogas. This creates the question of why Greece has not yet undertaken successful actions that could drive biogas adoption. To address this question, it is essential to first understand biogas technology and the actions related to this technology through the lens of Innovation Systems.

2.3 Innovation Systems (IS)

To better recognize the characteristics of biogas technology it is important to introduce the concept of innovation systems. This way it will be possible to categorize the different involved actors and understand the importance of policy actions designed to promote the innovation process.

2.3.1 Definition of Innovation Systems

The Systems of Innovation can be defined as all the crucial economic, social, political, organizational, and other factors that impact the advancement, spread, and utilization of innovations (Edquist & Charles Edquist, 2001). This approach has been initially defined by the work of Freedman (1987), Lundvall (1992), and Nelson (1993) with Edquist (1997) characterizing the dimensions of the SI approach (Edquist & Charles Edquist, 2001). Based on these dimensions, firms do not in general innovate in isolation, institutions are substantial elements in all aspects of the SI approach and shape the actions and associations between organizations (Edquist Charles, 1997).

The relationship between organizations and institutions is regarded as a complex, reciprocal relationship of mutual interdependence that affects innovation processes, thereby influencing both the performance and evolution of innovation systems (Edquist & Charles Edquist, 2001). For a clearer depiction, an Innovation System (IS) consists of multiple firms engaging in innovation and collaboration with educational systems, labor markets, and financial markets.

The exchange of knowledge, referred to as knowledge flows, is influenced by institutions such as rules, regulations, and culture, which influence and facilitate knowledge transfer. Additionally, these interactions have defined limits or boundaries (Borges et al., 2023).

In essence, an Innovation System (IS) is a collection of interconnected components and functionalities that produce observable patterns of behavior over time. External forces can constrain, trigger, or guide this behavior, but the ultimate outcomes are principally shaped by the interactions of various fundamental characteristics within the system (Meadows & Wright, 2008).

An overall characterization of the key activities in systems of innovation is provided by Edquist, (2009) and includes the establishment of R&D results and creation of new knowledge, competence building such as formal and informal learning, formation of new product markets, delivery of new product quality requirements, establishing and modifying organizations essential for fostering innovation in emerging fields, networking and collaborative learning among diverse organizations, creating and changing institutions, facilitating innovation with facilities and administrative support, financing of innovation and lastly provision of consultancy services.

Understanding certain Innovation Systems in the effort to accelerate energy and sustainable transition can be a key factor and influence how regulatory frameworks and policies affect innovation. As a result, multiple outcomes can be generated by this process such as a policy design to address the system failures identified by the innovation system analysis (Foxon et al., 2004). Additionally based on Foxon et al., (2004), the study of innovation systems can provide input in the design and realization of effective policies to provide incentives for innovation whereas, national innovation systems act as a network of institutions that dynamically develop, alter, and diffuse new energy technology (Tawney et al., 2015). At the same time, in the context of sustainability issues such as waste management and climate change, technological innovation has generally been regarded as an important aspect of the efforts to resolve these problems (Lanshina et al., 2018; Malhotra et al., 2019). These observations help form an understanding of the importance of the study of innovation systems in the context of energy transition as important policies, new technologies, and effective incentives can provide the environment to tackle the related sustainability issues.

2.3.2 Innovation Systems in the context of Biogas TIS

After providing a description of the basic characteristics of Innovation Systems and their importance in energy transition, it would serve the purpose of this study to further expand this subject into biogas technology. To do so, Biogas Technology should not only be understood as an Innovation System but also as a Technological Innovation System (TIS).

The innovation system framework can be studied under a national (NIS) (Freeman, 1993), Regional (RIS) (Cooke et al., 1997), sectoral, and global perspective while the focus on understanding the function of a technological field is concentrated on the study of the Technological Innovation Systems framework (Borges et al., 2023).

Based on Carlsson & Stankiewicz, (1991), a technological system can be defined as a network of entities interacting within a specific economic or industrial sector, operating under a certain institutional framework, and involved in the development, spread, and use of technology. The authors also focus on the existence of dynamic knowledge and competence networks. They additionally mention the multi-dimensional aspect of technological systems and the fact that in most instances, the various components (knowledge/competence networks, industrial networks/development clusters, and institutional frameworks) tend to be geographically interconnected with the nation-state constituting a natural border (Carlsson & Stankiewicz, 1991). In addition, the level of analysis of Technological innovation Systems can generally vary and it is possible to study a TIS at a global and a regional level (Wieczorek & Hekkert, 2012).

Existing literature related to biogas technology underscores its characteristics as a Technological Innovation System. In detail, the main functions of TIS framework are based on Bergek et al., (2008); Hekkert & Negro, (2009) who identify the main characteristics of these systems. As a result, it is possible to understand a specific Technological Innovation System by identifying the system functions such as existing entrepreneurial activities, knowledge development, knowledge diffusion through networks, guidance of the search, market formation, resource mobilization, and creation of legitimacy in a specific system. These functions are displayed in the Table 1 below:

Functions		Characteristics
F1	**Entrepreneurial Activities**	Commercial projects, contractors, demonstrations, experiments
F2	**Knowledge Development**	Evaluation and viability analyses, educational endeavors, research and development ventures, trial and prototype initiatives, lab tests, intellectual property rights, documentation, and scholarly works
F3	**Knowledge Diffusion**	Conventions, forums, seminars, collaborations, gatherings, cooperative initiatives and coalitions
F4	**Guidance of Search**	Established institutions: policy tools/objectives and aims, official regulations, directives, legislation, and norms Flexible institutions: unofficial interactions, commitments, anticipations, media coverage shaping expectations, beliefs, and aspirations
F5	**Market Formation**	Pricing strategies, Carbon dioxide taxes, tax incentives, feed-in tariffs, allocation limits, regulatory and incentive schemes
F6	**Mobilization or resources**	Human capital: skilled professionals Financial capital: grants and investments facilitated by entrepreneurial and governmental initiatives Material resources: natural resource accessibility Foundational infrastructure: educational institutions, refueling facilities
F7	**Creation of Legitimacy**	Interest groups, lobbying efforts, media influence, and technology promotion by entities and governments

		through awards, incentives, informational materials, and contests

Table 1 System Functions (Nevzorova, 2022; Wieczorek & Hekkert, 2012)

To be able to understand the systemic barriers related to the biogas technology this understanding of biogas as a TIS can help categorize the existing functions and dynamics observed and at the next stage proceed into identifying problems of the system. As a result, it is possible to examine the biogas technology under certain theoretical boundaries that have been studied in other countries. Certain country examples will be presented in the following part.

2.4 Biogas Innovation Systems: Country Examples

In light of this clear identification, it is possible to note the main characteristics of different TIS for biogas technology. The countries presented below were chosen outside of the successful EU cases and fall under a European and global perspective. Additionally as a country with certain systemic problems in the biogas sector Greece can be related to these cases with similarities in stakeholder relations, system outlook, and current growth.

In the case of Brazil De Oliveira & Negro, (2019) were able to examine the TIS structural-functional conditions that affect contextual influences based on the "*bundle of value chains*" perspective of technologies and thus developed an understanding of the mechanisms that function in the Brazilian Biogas Innovation System. As a result, this analysis identified actors involved such as government bodies, utility companies, private companies, intermediary organizations, research centers, financial organizations, universities, and farmers. The researchers were able to identify patterns of contextual influences which can later result in policy actions (De Oliveira & Negro, 2019).

In the same context of the Brazilian Biogas Innovation System, Borges et al., (2023) analyzed the barriers and drivers affecting the acceleration of the system categorizing the components as Technological, Institutional, Market, Economic, and Environmental. This analysis based on the basic functions of the TIS was able to shed light on the expansion of the Innovation System in the country and provide policy recommendations for the establishment of legitimacy. As a result, a new policy recommendation (RenovaGas) connected to the existing policies for Natural Gas could provide incentives via tariffs and credits that could open opportunities for producers in the market.

Similarly, a TIS framework analysis in Rwanda regarding the bio-digestion adoption in the country, was possible to highlight and analyze the Innovation System through the seven TIS major functions and at the next stage analyze the strengths, weaknesses, and blockages of the biogas TIS such as low level of entrepreneurial activities and the market formation functions. These blockages including other related barriers are making clear points for policymaking actions to support the deployment and diffusion of sustainable technologies such as bio-digestion. Finally, emphasis is given to the importance of a systemic perspective in policymaking related not only to technical but also organizational, institutional, and social elements, as a way to effectively address weak functions in the TIS (Tigabu et al., 2015).

An analysis of the Biogas TIS in Russia revealed the involvement of different sectors such as agriculture, industry, and energy in the development, of the biogas value chain. Through the TIS functions these sectors have significant roles in knowledge development, policy formation, and market dynamics while the competition between actors from other energy industries through lobbying hinders the development of biogas. At the same time, international actors and agreements shape innovation dynamics across different regions in the country. As a result, the TIS analysis in the country was able to generate policy suggestions such as waste disposal legislation, the introduction of soft loans to biogas producers, federal support programs, educational initiatives for biogas specialists, and actions for increased social awareness on biogas and its benefits (Nevzorova, 2022).

The existence of these studies and the recommendation output that is possible to be generated after the extensive analysis through the TIS framework is seen to be able to formulate policies that effectively target the system obstacles and the interactions with other competing industries. This showcases the importance of the analysis of biogas technology through the TIS lens and the contribution to tailored policy recommendations after a thorough understanding of the country-specific system.

Additionally, an analysis of the Swiss Biogas TIS was possible to identify development options for the innovation system. As a result, predicting the use of energy crops as substrates and the introduction of gas feed-in could bring new adjustments in the biogas technology and policies. The analysis was able to also identify key actors including engineering companies, farmers, other biogas operators (agro-biogas plants), biogas associations (e.g. Swiss gas industry VSG), financers (e.g. banks) food producers, and utility companies resulting in ultimately mapping out the Biogas industry. This analysis provided an understanding of the interactions between the actors, the specific institutions, and the regulations applied in the system (Markard et al., 2009).

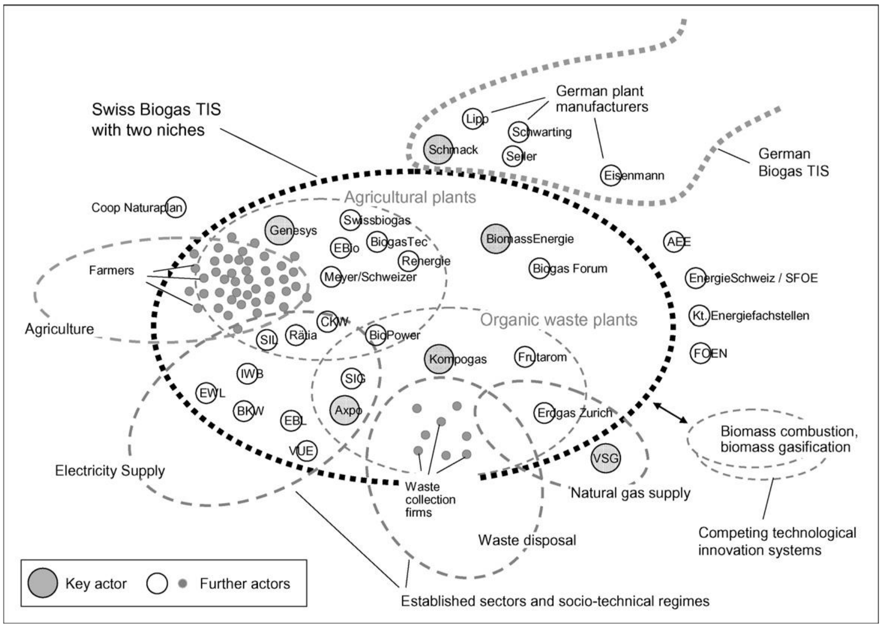

Figure 1 Actors in the Swiss biogas innovation system (Markard et al., 2009)

Following these studies, it can be concluded that through the Innovation Systems approach and especially the TIS framework it is possible to not only define and methodically pinpoint the characteristics of a system but also indicate the barriers and drivers of adoption.

These barriers can later assist in indicating policy actions that can help accelerate the adoption of a technology which in the existing case is biogas in Greece.

2.5 System Failure Framework

After defining the importance of understanding and analyzing the biogas system in Greece as a TIS it is equally important to set the theoretical framework for identifying the existing system failures. This chapter sets out the basic principles of the theoretical framework of System Failure and highlights its importance in the diagnosis of systemic issues. Additionally, the main components of the framework are introduced along with the framework's application in previous research.

2.5.1 Introduction to System Failure and Market Failure

Innovation systems are complex networks consisting of various actors and institutions involved in the creation, diffusion, and utilization of knowledge. Traditional market failure frameworks, which focus on inefficient resource allocation, are insufficient to address the complex dynamics within these systems. Market failure typically refers to situations where market mechanisms fail due to externalities, imperfect market structures, and information asymmetries, among other factors (Dodgson et al., 2011). These principles, do not adequately capture the systemic issues that hinder innovation, requiring a broader framework such as the system failure approach.

The market failure approach has been consistently used to justify public intervention in innovation systems, mainly due to underinvestment in R&D and innovation. Market failures outline conditions where private markets are unable to allocate resources efficiently, leading to suboptimal outcomes. Key factors contributing to market failures include external influences, the nature of public goods, and the existence of natural monopolies (Dodgson et al., 2011). However, this approach often is unable to address the complex dynamics of innovation systems, such as the roles and interactions of different stakeholders not directly related to specific markets (Bleda & Del Río, 2013).

2.5.2 System Failure Framework

The System Failure Framework emerged to address the limitations of the market failure approach by focusing on the broader systemic issues that hamper the development and performance of innovation systems. This approach examines interactions between numerous actors and institutions identifying failures that market mechanisms cannot directly address (Bleda & Del Río, 2013).

2.5.2.1 Choice of the System Failure Framework

One of the main objectives of this study is centered on understanding the challenges in the Greek Biogas Innovation System by identifying systemic problems that are related to all the stakeholders. Unlike market failure, which focuses on resource allocation inefficiencies, the system failure framework addresses more extensive interactions in the system. This framework is considered useful for policy design that fosters innovation by addressing these identified systematic issues (Bleda & Del Río, 2013; Klein Woolthuis et al., 2005).

As a result, the system failure framework is chosen for its ability to present a comprehensive overview of the system issues that hinder innovation. By considering the contributions and interactions of all stakeholders, this framework can identify problems that are in many cases overlooked by market failure approaches. Additionally, as Bleda & Del Río, (2013) argue, this approach complements the market failure logic by looking at broader dynamics and interactions within an innovation system, including the roles of various actors and institutions.

2.5.2.2 Characteristics of the System Failure Approach

Incorporating the key functions of the TIS, the systemic failures framework directly relates to the problems and limitations in these functions that contribute to the system's performance (Bleda & Del Río, 2013). In the same context Edquist, (2011) characterizes this identification of system failures as a diagnosis process that is linked to the efficiency of an innovation system and can be used effectively for policy design and action. Focusing on activities such as research and development, provision of organizations and institutions, and financing of innovations and incubations, performed by both private and public organizations, the framework emphasizes the importance of understanding the system's performance and how it operates. At the same time, it is important to analyze the division of labor between private and public organizations in the innovation system as well as their role and activities in the system to then proceed in designing the needed policies.

The system failure approach has the ability to present a clear differentiation between the different types of system failures and the related stakeholders that could be able to address them. As a tool it can more efficiently point out the systemic problems than the market failure approach and at the same time indicate the actors that should address these issues (Klein Woolthuis et al., 2005).

The reason behind the need for such a framework mainly relates to the complexity of the evolutionary nature of innovation. As government bodies do not rely on the open market to direct innovation performance, the needed policies and regulations should fit the specific needs of a system. As a result, the system failure framework, and through its diagnostic analysis provides a practical approach considering the interconnections between the various actors and as a result, this method can assist in designing adaptive policy actions (Dodgson et al., 2011; Edquist, 2011).

2.5.2.3 Main Components

Systemic failures can be categorized into four main types as has been done by (Klein Woolthuis et al., 2005):

Infrastructural Failures: These failures occur when there is underinvestment or inefficient allocation of resources in physical and technological infrastructure crucial for innovation. Infrastructural failures can hinder the development and diffusion of new technologies by limiting access to essential resources and facilities (Smith, 2000). For example, inadequate transportation and communication networks can impede the efficient transfer of knowledge and resources within the innovation system.

Institutional Failures: These encompass both formal and informal institutional mechanisms that may hinder innovation. Formal institutional failures include regulations, standards, and policies that create barriers to innovation, while informal institutional failures involve social norms, values, and cultural factors that influence behavior (Carlsson & Jacobsson, 1997; Smith, 2000). For instance, overly stringent safety regulations may restrain experimentation, while a culture of risk aversion may prevent entrepreneurial activity.

Interaction Failures: These failures include strong network failures (close links leading to myopia) and weak network failures (poor connectivity leading to insufficient knowledge exchange). Strong network failures occur when actors within the innovation system are overly reliant on existing relationships, leading to a lack of diversity in perspectives and ideas (Carlsson & Jacobsson, 1997). Weak network failures, on the other hand, result from inadequate collaboration and communication among stakeholders, which can limit the flow of knowledge and resources.

Capabilities Failures: Firms lacking capabilities to learn and adapt to new technologies experience capabilities failures. These failures are often seen in small and medium-sized enterprises (SMEs) that lack the resources and expertise needed to innovate (Malerba, 2002; Smith, 2000). Addressing capabilities failures requires targeted support for skill development, knowledge transfer, and resource allocation to enhance firms' innovation capacities.

In total, the SI-policy framework is presented below in Table 2:

Actors (missing actors) / ***Rules (system failures)***	**Demand** •Consumers •Large buyers	**Companies** •Large firms •MNCs •SMEs •Start-ups	**Knowledge institutes** •Universities •Technology institutes	**'Third parties'** •Banks, VCs •Intermediaries, consultants •Sector organisations, employers
Infrastructural failure: ICT, roads, railroads, telecom, ..				
Institutional failure: • Hard: laws, regulations, …				
• Soft: norms, values, …				
Interaction failure • Weak network failure				
• Strong network failure				
Capabilities failure				

Table 2 The SI-policy framework (Klein Woolthuis et al., 2005)

2.5.2.4 Application of the Framework in Previous Research

The System Failure Framework has been effectively applied in various contexts to analyze and address systemic issues in innovation systems. For instance, the UK innovation systems for renewable energy technologies identified several system failures, such as gaps in moving technologies along the innovation chain, which hindered commercialization. This analysis emphasized the need for a stable and consistent policy framework to enhance innovation outcomes (Foxon et al., 2004).

In their study, Foxon et al., (2004) emphasized the necessity of overcoming infrastructural and institutional obstacles to advance the development and implementation of renewable energy technologies. They pinpointed particular challenges, including insufficient grid infrastructure and inconsistent regulations, which hindered the sector's expansion. Utilizing the system failure framework, the researchers suggested specific interventions to tackle these problems and facilitate the commercialization of renewable energy technologies.

Another example of the framework's application is seen in the analysis of the Swedish innovation system for environmental technologies. Bergek et al., (2008) used the system failure framework to identify systemic problems that hindered the development and diffusion of environmental technologies in Sweden. They found that interaction failures, such as weak collaboration between research institutions and industry, were significant barriers to innovation. The study recommended enhancing network-building activities and fostering stronger partnerships between stakeholders to address these failures.

These studies showcase the framework's ability to differentiate between various types of failures and the related stakeholders, which makes it a practical tool for policy design. By focusing on systemic interactions and the division of labor between public and private entities, the framework provides actionable insights for fostering innovation (Dodgson et al., 2011; Edquist, 2011).

Utilizing this approach in the analysis of the systemic barriers of the Greek Biogas Innovation System will assist in categorizing the existing system's imperfections and the stakeholders related while it will additionally help direct the needed actions to address them.

2.6 Stakeholder Participation & Participatory Design

Engaging stakeholders in the innovation process is crucial for addressing system failures and ensuring the success of innovation policies. The participatory design framework emphasizes the involvement of diverse stakeholders in the design and implementation of innovations. This approach advances collaboration, enhances stakeholder inclusion, and improves the relevance and sustainability of innovations.

Through the use of this approach and its integration into the use of the system failure framework, it can be possible to not only understand the existing problems in the Biogas TIS but also identify ways that the technology can be supported by stakeholders that were previously not directly involved with biogas.

2.6.1 Participatory Design Framework

Participatory design (PD) has its roots in the democratic movements of the 1960s and 1970s, originally focusing on workplace technology to democratize the work environment (Greenbaum, 1993). Over time, PD has evolved to include broader contexts and diverse domains such as healthcare, robotics, and work with refugee populations (Jesper Simonsen, 2012). The fundamental principle of PD is participation, where stakeholders are actively involved in the design process to ensure that their needs and perspectives are integrated into the final product (Ten Holter, 2022). This participatory approach is intended to improve the alignment between technological developments and societal needs, thereby enhancing trust and acceptance of new technologies (Ten Holter, 2022).

2.6.2 Incorporating Stakeholder Perspectives

Understanding and incorporating stakeholder participation is particularly crucial in the context of biogas technology. Biogas projects often involve multiple stakeholders, including biogas producers, farmers, third parties, universities, minority groups, and immigrant organizations. Each of these stakeholders has unique perspectives and concerns that need to be addressed to ensure the success of biogas innovations.

Ten Holter, (2022) highlights the importance of inclusivity in PD, which aims to build a bridge between innovators and the public. This approach seeks to create innovations that are not only technologically advanced but also socially acceptable and beneficial. By involving stakeholders in the design process, PD ensures that the potential negative impacts of new technologies are anticipated and mitigated, thereby providing democratic legitimacy to innovations.

In their work, Suboticki et al., (2023) emphasize the concept of co-creation within participatory frameworks. Co-creation involves equal collaboration among all participating actors, allowing them to have significant control over the process and outcomes. This method enhances procedural justice by facilitating fair participation processes and distributional justice by ensuring that the outcomes are fair and beneficial to all involved groups. Co-creation also allows for the inclusion of marginalized voices, thereby widening the range and diversity of participants and improving the overall decision-making process (Suboticki et al., 2023).

Additionally, Bourdin et al., (2020) underscore the importance of regional governance and the coordination of actors in the development of biogas projects. Their research shows that local hostility to biogas plants often arises due to concerns about environmental impact, safety, and property values. By involving local residents and other stakeholders in the planning and decision-making process, project developers can address these concerns and enhance social acceptability. Effective stakeholder participation can help identify and address potential barriers to innovation, thereby fostering a more supportive environment for biogas projects (Bourdin et al., 2020).

As a result, incorporating various stakeholder perspectives through this study and taking into account the views of directly and indirectly involved stakeholders or communities will support the inclusion of all the members affected by biogas in the system. A democratized way of hearing all voices and working towards addressing all needs can, as it has been understood from above, help the acceptance of the technology minimizing potential negative effects.

2.6.3 Integration with the System Failure Framework

In conclusion, the integration of stakeholder participation in the context of participatory design is essential for addressing systemic failures in innovation systems, particularly in the context of biogas technology. By involving diverse stakeholders in the innovation process, project developers can identify and address potential barriers, ensure support for biogas projects, and enhance the overall effectiveness and sustainability of biogas innovations.

As a result, participatory design (PD) can help ensure that the solutions provided by the implementation of the recommendations from the System Failure Framework are targeting users and local communities and can be widely accepted. This integration allows both frameworks to effectively target the main system problems while ensuring that the proposed changes include all of the, directly and indirectly, related stakeholders.

2.7 Literature Summary

This chapter provided a detailed review of the importance of biogas as an energy source in order to achieve the EU's targets for carbon neutrality by 2050. Biogas and biomethane are strong solutions as they can significantly reduce emissions across the value chain, addressing energy crises, fossil fuel depletion, high costs, and environmental issues. The main technology behind biogas production, anaerobic digestion, has a high efficiency and readiness level and is able to process diverse organic feedstocks making the biogas technology highly adaptable.

Europe, particularly countries like Germany, Italy, and France, has made substantial progress in biogas adoption, driven by supportive policies, financial incentives, and strong stakeholder networks.

The Innovation Systems (IS) approach, especially the Technological Innovation Systems (TIS) framework, is vital for understanding the dynamics of biogas technology adoption. This framework identifies key functions such as entrepreneurial activities, knowledge development, and market formation, which are essential for technology diffusion.

Under the TIS approach, the System Failure Framework can address the broader systemic issues, including infrastructural, institutional, interaction, and capabilities failures, which can hinder innovation.

Additionally, integrating stakeholder participation through participatory design makes it possible for this study to understand the systemic barriers preventing the growth of the system, in the Thessaly region of Greece from the perspectives of directly and indirectly involved stakeholders. This direction could safeguard that solutions are inclusive, addressing the needs and concerns of all involved parties, and thus enhancing the overall effectiveness and acceptance of biogas innovations.

In the next part of the study, a specific focus will be given on Greece, the presence of biogas in the country, and the Thessaly region while the need to address the needs of communities will be further expanded after the catastrophic events of a natural disaster such as the Daniel storm.

3 The case of Biogas in Greece

This part of the study presents information about the Greek case of biogas. This information can help understand in detail the production of biogas in the country and the stakeholders identified through the literature. Another important part of this section focuses on strengthening the case of why Greece is a country with biogas potential and what existing studies have shown concerning certain barriers that hinder its expansion. Finally, information on the effects of the Daniel storm is presented to highlight the existing problems Thessaly communities face. All of these points provide the information needed to understand the existing conditions in the country for the purpose of conducting this research.

3.1 Biogas in Greece

Biogas production in Greece commenced in the early 2000s, and up until 2010, sewage and landfill facilities primarily dominated the country's biogas sector. Between 2010 and 2019 the development of plants rose from 17 to 53 with the addition of a large landfill site that started its operation in 2020 and an installed electric capacity of 3.52MW. The key point of this slow but evident adoption is linked with the FiTs of the Greek government in its 3851 Renewable Energy Law in 2010 (European Biogas Association, 2020).

The limited number of biogas plants until 2010 has been targeted by the Greek government and with legislation No.3851/2010 and its revision in 2014 (No.4254/2014) the Feed-in-Tariffs for electricity production have been increased from 75€/MWh to 190-230€/MWh. This measure increased the interest in biogas production and as a result benefited the development and planning of additional agricultural, organic waste and wastewater plants (Markou et al., 2017). The recent establishment of anaerobic digestion practices in Greece has seen important growth and by 2019 the electrical power installed was 73.6 MW from 49 biogas plants (Spyridonidis et al., 2020).

In general, anaerobic digestion in the country is mainly used as a waste management practice without an important focus on energy and biogas production. At the same time, the country's energy needs are mainly based on fossil fuels (local-based lignite, imported petroleum, and natural gas), and 22% of local production is based on Renewable energy sources (RES) (Aravani et al., 2022).

Compared to other RES, biogas in Greece lies in a smaller scale of production. The installed capacity based on 2016 as can be seen in the graph below accounted for a small percentage of the total installed RES and was significantly low compared to the wind power and PV (photovoltaic) capacity.

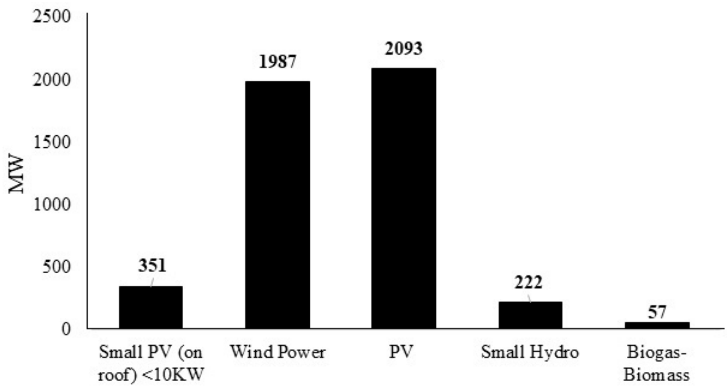

Figure 2 Installed RES in Greece, 2016 (Alatzas et al., 2019)

While European countries prioritize biomass utilization for the purpose of energy (electricity and thermal energy) production, it is observed that in Greece large amounts of biomass are disposed in the environment, in landfills, or burned in fields by farmers, posing a great environmental risk (Alatzas et al., 2019).

3.1.1 Types of feedstocks and biogas potential

In this section, the main types of feedstocks for the production of biogas will be introduced. This analysis is based on the feedstocks available in Greece and their potential; for biogas generation.

The potential for biogas production from such residues has been calculated in different publications providing strong indications regarding the management of these wastes and the related benefits. In the section Agricultural residues, the main wastes related to agricultural activities are analyzed and in the section Animal wastes and other types of waste, other types such as animal residues and municipal wastes are presented. Overall Total biogas production potential showcases the biogas potential which accounts for MW (megawatts) of energy after the utilization of these wastes.

3.1.1.1 Agricultural residues

With more than 70% of its total area related to agricultural activities Greece has evident and high biomass potential. Among the different types of agricultural residues, olive oil residues, tobacco, sugar beets, potatoes, and vegetables are characteristic examples of feedstock types that can be used for biogas production and are produced mainly in Thessaly, Eastern, Central and Western Macedonia and Crete (Aravani et al., 2022). These residues amount to an estimated total of 19.005,490 t/y and 48% of this amount is exploited for non-energy or other traditional energy applications leaving 40 to 45% of unexploited quantity (Vlyssides et al., 2015).

A relevant category also includes agro-industrial residues produced mainly by the olive industry, cheese tomato, and beer industries with an estimated annual production of 13.2 Mt per year (solid and liquid wastes)(Aravani et al., 2022). Studies related to the digestion of agro-industrial wastes (such as olive oil mill wastewater) or their co-digestion with other types of wastes such as animal wastes (poultry manure) have been proven to produce high methane yield and also achieve the treatment of the wastes at the same time (Thanos et al., 2021). In total, the estimated energy potential that could be achieved coming from agricultural residues can reach up to 11TWh (Aravani et al., 2022). Even if this estimate can be considered relatively high, especially if it can be compared to Greece's 2022 47.5 TWh electricity consumption (Enerdata, 2022), it serves this study to point out the increasing potential that exists only in the agricultural sector.

Energy Crops are additionally a potential source of biomass feedstock and specific to the country studies have examined the potential of their use and the related challenges. Markou et al., (2017) conducted a techno-economic analysis of different energy crops and their potential contribution to a biogas plant in terms of energy recovery and financial contribution while (Panoutsou, 2008) also stresses the potential use of energy crops by farmers and their perceptions regarding their potential adoption.

3.1.1.2 Animal wastes and other types of waste

Defined also as livestock manure animal manure includes wastes from livestock and poultry and all the related wastes of these activities. In Greece, the production of animal manure is significant due to the country's animal activity including sheep, goat, cows and calves, swine, and pullets breeding. The estimated animal wastes amount up to 26,952,500 t/y and the common practices among farmers where their use as fertilizers or the combustion for heat generation while there is an existing energy potential of 66TWh that remains unexploited (Aravani et al., 2022; Vlyssides et al., 2015). Additionally, food waste constitutes a respectable but unexploited residue in Greece while municipal waste is being managed and recycled at 17% (Papadopoulou et al., 2018).

3.1.1.3 Total Biogas Production Potential

Overall, the potential for biogas production is estimated to be able to highly contribute to the country's energy needs. The potential electricity production could be between 4.9-7.9 TWh (Vlyssides et al., 2015) while another study by (Aravani et al., 2022) has estimated an energy output of 77 TWh considering all the waste types. These numbers contribute to formulating an understanding of the country's strong biogas potential and energy production capabilities by utilizing its agricultural, agro-industrial, animal, and other residues.

3.1.2 Biogas Innovation System and Stakeholders

After analyzing the existing waste practices, biogas potential, and the current development of biogas in Greece it would serve this study to further expand into identifying the biogas acting stakeholders and related organizations, projects, and developments. This can shed light on the characteristics of an innovation system and can be valuable for the analysis of the Greek Biogas Innovation System.

3.1.2.1.1 Biogas Producers

Biogas Producers include mainly biogas plants such as solid waste landfills (SWL), municipal wastewater treatment plants (MWTP), and biogas agricultural plants. Plants such as the the 11.4MW wastewater plant of Psyttalia, or the 23.5MW solid waste landfill of Ano Liosia contribute to the waste management and utilization of the produced residues (Vlyssides et al., 2015; Zafiris, 2016). At the same time, the number of agricultural biogas plants has been rising in the country and new units are being installed such as a 6MW plant and a 1MW plant in Thessaly and additional cases of 1MW in Northern Greece or Rhodes (BIOGEST, 2021; KOHLER, 2016; Renewable Energy Magazine, 2023). It is also important to note that Thessaly is a region where multiple biogas plants operate with an installed capacity that constitutes approximately 50% of the entire Greek agricultural biogas installed capacity (Yfantis Alexandros, 2023).

As it has been stated, the importance of utilizing and managing the residues produced by agricultural activities is significant. Being the main producers of agricultural biomass and agricultural wastes, farmers have an important role in the Biogas Innovation System as their actions to collect and gather their residues create demand for the waste (Moustakas et al., 2020). As a result, considering the potential of the different residues and their abundance in Greece, farmer engagement plays a crucial role in the realization of the estimated biogas generation potential. At the same time, the role of the farmers in biogas production needs to be further investigated in this study as the analysis of the networks, cooperations, and actions of this stakeholder group need to be further expanded.

3.1.2.1.2 Government Bodies and Third Parties

One of the major stakeholders related to biogas, the Hellenic Association of Biogas (HABIO), was established in 2018 to support sustainable growth in the biogas industry. The association aims to advance the adoption and utilization of renewable gases, including biogas and biomethane, on a national scale through coordinated advocacy efforts, information sharing, research studies, and participation in European projects and initiatives. The association currently counts 6 years of activity and 48 members with a combined installed capacity of 77MW in electricity production (HABIO, 2024).

The Governmental bodies, having administrative, policy-making, and institutional roles are a key decision-making body (Panoutsou, 2008). In the context of Bio-economy, where biogas is also included, the main governmental bodies and active institutions are based on Papadopoulou et al., (2018) the Ministry of Environment and Energy, the General Secretariat of Research and Innovation, and the Ministry of Rural Development and Food. Additionally, the authors include in their analysis of 2018 a detailed table (Table 3) that provides a useful representation of all active institutions related to the bioeconomy. Thus, the table below can be valuable to understanding the further context of the bioeconomy that includes the biogas technology and the institutional bodies that surround it.

Relevant national strategies	The Rural Development Programme (2014-2020) National Climate Change Adaptation Strategy (NCCAS) National RIS for Smart Specialisation • Part 5.4 on Energy • Part 5.5 on Environment and Sustainable Development National Strategic Framework for Research and Innovation
Key national stakeholders	General Secretariat of Research and Innovation (Under the auspices of the Ministry of Education) Ministry of Rural Development and Food Ministry of Environment and Energy
Research Institutions	Hellenic Center for Marine Research Center for Renewable Energy Hellenic Agricultural Organization (HAO) DIMITER Centre for Research and Technology-Hellas (CERTH) The Agricultural University of Athens The Center for Renewable Sources and Efficiency (CRES)
Academic programmes	MSc in Bio-economics Pireaus and Athens University The International Hellenic University's MSc in Bio-economy: Biotechnology and Law
ThinkTanks/Clusters	The Greek Bio-economy FORUM The Cluster of Bioenergy and Environment of Western Macedonia (CluBE)
Other Labs/ Institutes	The Bio-economy and Sustainable Growth Laboratory of the Department of Economics of the University of Piraeus The Institute of Bio-Economy and Agri-Technology (iBO) of the Center for Research and Technology – Hellas (CERTH)

Table 3 Active institutions related to biogas and bioeconomy (Papadopoulou et al., 2018)

3.1.2.1.3 Universities and Knowledge Institutions

As stated by Panoutsou, (2008) bioenergy in Greece can be considered as fragmented and highly idiosyncratic as a limited number of institutional bodies is related to research activities in the field, and the information transmission between universities, companies, and industry is restricted and, in many cases, unorganized. An example of important development and cooperation between academia and other actors is the Waste4Think project developed between the National Technical University of Athens and the municipality of Halandri, Athens under the European program HORIZON 2020 for the purpose of infrastructure development, energy production, and food waste management such as food waste biomass (Municipality of Chalandri, 2020; Papadopoulou et al., 2018). Such an example highlights the importance of existing actions and initiatives however the existing actions and innovative output and program development need to be further identified in the context of the Greek Biogas Innovation System.

3.1.2.1.4 Communities

Energy generation from organic resources such as biomass gives the opportunity to industrial, or farming-related stakeholders to benefit but also to local communities and the general public (Panoutsou, 2008). Initiatives at a community level related to biogas have not yet been effectively developed, however, there is existing potential to implement community energy and social innovation in the efforts to achieve energy transition. Based on these efforts several programs have been implemented in Europe including the ISABEL program with an aim to empower local communities in Greece and other European countries for the production of biogas. Facilitating the research on a specific region of Greece (Central and Eastern Macedonia & Thrace) it was also possible to identify the characteristic barriers and facilitators for biogas production at a social innovation level and produce valuable results about community involvement in biogas production (ISABEL, 2017a).

3.1.3 Greek Targets in Biogas Production

3.1.3.1 Failed Production Goals

Despite its significant growth in terms of biogas production, the country has not met its previous NREAP targets of 210MW as it generated 78MW. The new NREAP (reformed into NECP) target established in 2019 has set a goal of 1600 GWh meaning a steady yearly growth of 100MW by the target year (European Biogas Association, 2020).

Based on the reformed National Energy and Climate Plan (NCEP) in 2023, one of the strategic priorities of Greece related to the "Bio-economy" are investments for the development of a national industrial agricultural production of advanced biofuels and biogas in order to be transformed into biomethane. Based on this reformed plan Greece expects to reach a 2.1 TWh production of purified biogas by 2030 reaching a production of 3.3 TWh in 2035 (Hellenic Republic, 2023). In addition, it is important to mention that the existing regulatory framework for the production of biomethane is currently under preparation and expected to be issued in 2024 (Hellenic Republic, 2023).

The above data related to the existing production, targets, potential production, and the existent regulatory framework highly indicate a problematic situation in the country compared to many other European states and this raises the question regarding the barriers that might exist and the level of inclusion of all the related stakeholders.

Past analyses on the barriers in Greece indicate certain barriers that focus on especially small-scale biogas plants in the country. In a 2008 study, key barriers to biogas adoption included low awareness among farmers and industries, high investment costs, limited economic incentives, market challenges due to the non-liberalized electricity market, and institutional/regulatory issues hindering commitment and efficiency in promoting biogas potential (Sioulas Konstantinos, 2008).

In addition to these findings, Panoutsou, (2008) conducted in 2008 an extensive analysis examining the barriers to bioenergy adoption and conducted a survey on farmers and end-users of the region of Rodopi. From these findings, bioenergy scheme adoption was studied on a national and local level and the perspectives of stakeholders at the two levels identified several needs on a technological, economic, policy, sustainability, and innovation level. The study concluded that in Greece, specifically within the examined region, tackling technological, economic, social, and environmental challenges was imperative for the successful structuring of the needed infrastructure. Moreover, fostering collaborative partnerships among stakeholders was considered essential for advancing the development of the bioenergy industry (Panoutsou, 2008).

Regarding community-based projects, identified barriers relate to different aspects. The financial crisis has profoundly impacted the ability of financial institutions to finance new investments while the volatile financial and regulatory landscape breeds uncertainty for new investments. Moreover, bureaucratic complexity adds complications and discourages local stakeholders from participating in biogas initiatives. In social /community terms the potential use of biogas by-products, such as compost and heat, remains uncertain due to Greek farmer's lack of awareness about the adding value of compost forming a negative perception towards it. One key barrier also constitutes the fact that local communities exhibit a moderate to low level of understanding and awareness of biogas (ISABEL, 2017b).

3.1.3.2 Missing Barriers for Adoption and Systemic Problems

Despite valuable insights from studies conducted in 2008, the landscape surrounding biogas adoption in Greece has evolved significantly. Changes in legislation, economic conditions, the liberalized electricity network, and technological advancements necessitate a fresh examination. The slow but evident growth of biogas adoption in the country, coupled with the failure to meet NREAP targets, underscores the existence of barriers.

While early studies (Panoutsou, 2008; Sioulas Konstantinos, 2008) identified key obstacles, the current literature lacks recent insights into overcoming these barriers and further understanding of how the biogas innovation system is constructed. This research addresses the literature gap by employing a qualitative approach to understand the contemporary challenges stakeholders face and identify imperfections in the innovation system to provide valuable policy insights that can later accelerate biogas adoption in the current Greek context.

3.2 Unexpected Events that impact the biogas sector

While the question remains about the possible barriers to the adoption of biogas technology in Greece, the impact of nature is also an issue unforeseen by the systemic analysis eye. Greece had the tragic fate of experiencing such a phenomenon that not only destroyed infrastructure but also left whole communities in a weak position.

In 2023, Greece experienced one of the most severe disasters in its recent history. The Daniel storm caused catastrophic flooding across the region of Thessaly, leading to widespread damage, loss of life, and significant economic effects. The flood caused severe destruction of infrastructure as streets turned into dangerous rivers damaging buildings, bridges, and entire villages (CNN, 2023; The New York Times, 2023).

As a result of the storm, thousands of people have been left without a home while local businesses and other infrastructure such as schools suffered large damage. As it can be understood, local communities suffered during this period with large needs in food, medical supplies, housing, psychological support, and the loss of employment being some of the immediate and also long-term effects of this catastrophe (UNICEF, 2023).

The Greek Government and local authorities initiated response measures in order to support the affected citizens and businesses. The government launched an aid platform and provided financial assistance to affected individuals including financial aid of 10000 euros for housing assistance, business support financial aid of 4000 euros, and 6600 euros for housing equipment support. In addition, a housing assistance framework was developed covering 80% or reconstructions and covered 70% of business and livestock farm damages while tax obligations were suspended (Evelyn Karakatsani, 2023).

While the damages have not yet been seen in the long term there is a need for more proposed measures and support for affected citizens and businesses in order to minimize the impact of such catastrophes in the future and help communities receive support(Evelyn Karakatsani, 2023).

3.3 Identification of Literature and Research Gap

While the situation of biogas in Greece has been expanded to a certain extent the reasons related to the technology's slow adoption remain. Though many European Countries have created efficient systems around Biogas Technology it is yet not clear what are the reasons for slow development in Greece.

Furthermore, in comparison with other RES in the country, biogas technology has seen slow adoption even though the available resources are existent and capable of covering a large amount of the country’s energy needs.

The existing literature as mentioned in Missing Barriers for Adoption and Systemic Problems has identified certain elements linked to the problematic biogas adoption, however, as discussed there is a need for a more contemporary analysis. Such an analysis should take into account existing problems of the current environment in the country and issues such as the impact of communities or natural disasters that have not yet been analyzed.

This need for such a contemporary analysis not only addresses the issue of the adoption of biogas but also takes into account the opportunity of including in the system, stakeholders that have not been encouraged to actively participate in the past.

As a result, this can provide the ground for policy interventions that are related to a wider audience and address issues connected to both the technology adoption and also the importance of community participation, a characteristic that has the potential to support the biogas diffusion through the technology acceptance and the community active involvement.

4 Methodology

4.1 Choice of Research Methodology

The identification of the Greek Biogas Innovation System and the System Failures along with the recommendations towards a more inclusive system design in Greece required the application of a qualitative design.

Such an approach has been implemented in also other related studies. In a study to understand the diffusion of domestic biogas technologies from developing and emerging countries Ortiz et al., (2017) approached the problem in a similar way and applied a qualitative analysis of scientific literature to test categories proposed by the conceptual model of the study.

Furthermore, to provide an understanding of the policy context of the diffusion of bioenergy in Greece, Panoutsou (2008) also applied a qualitative approach. By analyzing the framework, policies, and key affecting factors and later identifying key stakeholders the researcher later focused on a case study in a specific region for a more in-depth analysis.

The studies above indicate the importance of providing a qualitative approach when understanding the barriers to innovation adoption and it can be highly valuable for this research to follow a similar approach.

Thus, by implementing a similar strategy, the research methodology used in this thesis was a qualitative case study approach. The case study approach was selected as the main purpose of this research is to understand the dynamics in the Greek Biogas Innovation System and as a research strategy, the case study approach fulfills this requirement (Eisenhardt, 1989).

Based on Eisenhardt, (1989), the method of constructing theory based on case study research involves defining the case study into various stages, which serve as a guide for conducting the research. These steps are explained in the chapters below.

4.2 Research Question

As has been defined in the Problem Statement and Research Questions, the main research question of this Master thesis is:

"What systemic barriers are preventing the growth of the Greek Biogas Innovation System?"

This initial definition of the question focuses on identifying the elements that influence the slow adoption of biogas in Greece. The adoption of biogas is understood initially under the context of the biogas technology innovation system (TIS). It is in that innovation system that this research focuses on understanding the System Failures that occur. Additionally in order to democratize the innovation around the technology and include more stakeholders the study finally focuses on the approaches of stakeholder inclusion and community empowerment. To cover the above matters and provide a well-structured identification of the systemic problems the research focuses on the questions below:

- What are the characteristics of the Greek Biogas Innovation System?
- What are the system failures related to the biogas adoption in Greece based on stakeholders directly and indirectly related to the biogas innovation system?
- What are the challenges of community inclusion in the Greek Biogas Innovation System and how can these issues be surpassed to address the community needs through engagement?

4.3 Selecting Cases

For the selection of the case in the Greek context the region of Thessaly was selected. The reason for choosing this region to conduct this case study is based on multiple criteria. One of these criteria involves the selection of an extreme situation (Eisenhardt, 1989) and Thessaly region falls under this specification based on its high production (compared to other Greek regions) and existing biogas sector.

At the same time due to the region's environmental issues such as the catastrophic floods due to Daniel Storm in September 2023 (NOS, 2023), Thessaly is an important region for study purposes and identification of community support and empowerment in light of the recent incidents.

Thessaly is a region in Central Greece with a total area of 14036 km^2 and a population of around 730,000 inhabitants. The capital of the area is Larissa and the ground is 50% mountainous/semi-mountainous and 50% flat. The region has also the biggest and most productive agricultural plain in Greece, the Thessaly Plain, in the center of the region. Thessaly is also ranked among the highest biomass potential regions in Greece as a result of the intensive agricultural activities in the area (Moustakas et al., 2020). Additionally, as it has been stated in The case of Biogas in Greece, Thessaly contains the largest number of biogas plants, thus presenting an extreme situation of biogas production in Greece.

The selection of Thessaly, thus, provides a rich case as a region for this study. Apart from its existing high production, Thessaly still has the potential to use the existing agricultural and livestock residues with the total residues being able to produce approximately 708-1091GWh/year in electricity and 1112-1577 GWh/year in thermal energy from potential biogas production (Argyropoulos et al., 2023). This potential biogas production is still underexploited by the biogas industry as it is observed that there is no demand for the residues from the agricultural and farming activities with the farmers resulting in not making any additional attempts to collect and concentrate the residues (Moustakas et al., 2020).

The characteristics of this region serve this specific study as there is an observed lack of development and unutilized biogas potential that needs to be examined. Furthermore, this case represents a characteristic example of a Greek region with high potential, recent events that damaged the area and space for community inclusion. As a result, a study located in that area can produce generalizable results for the country that can represent similar cases in other Greek regions.

4.4 Data Collection and Analysis: Qualitative Interviews

The research process of the case study will combine multiple data collection methods such as qualitative interviews, and literature data provided by a targeted literature review focused on Greece and Biogas TIS.

This targeted literature review applied during the Thesis helped understand the existing problem, collect additional data, and validate certain findings and is presented in Theoretical background and The case of Biogas in Greece. This review provides a comprehensive analysis of the case of biogas in the region of Greece and the practical applications of the TIS, System Failure framework, and Participatory Design approach in biogas and other renewable technologies. This step was crucial as it provided the basis for the above aspects to be understood and covered before proceeding to the interview process thus providing sufficient knowledge and content for the interviews and analysis of the findings.

To approach the three sub-questions, qualitative interviews were performed with stakeholders from the region of Thessaly and stakeholders with activities related to biogas production or innovation in the region. Through the application of semi-structured interviews, combining closed and open-ended questions, the conversation with the stakeholders was focused on predetermined agenda topics, while also allowing for the exploration of entirely unexpected issues (Adams, 2015).

This part acted as an initial step in exploring the characteristics of the Biogas Innovation System as the interviews explored the experiences of participants and the issues related to the research question using open-ended questions (Tong et al., 2007).

To conduct a rigorous research and follow a transparent reporting method the interview organization followed the methodology by Tong et al., (2007) and the criteria checklist the authors constructed. This method assisted in reporting important aspects of the researcher, study methods, context of the study, findings, analysis, and interpretations.

4.4.1 Research Team and Reflexivity

The interviewer in this study was the main author of this Master's Thesis Research. Regarding the credentials of the interview facilitator, the researcher is a master's student and through these studies and current occupation, the author has acquired the necessary knowledge to conduct this study.

Even though the researcher does not hold specific experience in conducting qualitative interviews, the skills, and experience grew during this master thesis research and were further developed during the course of the interviews.

The researcher engaged in a neutral relationship with the participants and specific information regarding the interviewer's background was shared. Such information included the researcher's motivation for conducting the research, the research topic, and the research objective including answering possible questions the participants had. The interviews were held under the TU Delft guidelines and procedures and approval for Human Research was provided by the Human Research Ethics Committee (HREC).

4.4.2 Study Design

4.4.2.1 Participant Selection

The initial aim of this study was to include a variety of different participants and as a result, gather information and the views of as many as possible different stakeholders involved in the region's biogas sector.

Participants included key stakeholders involved in the biogas sector of the region and as explained in the four categories of the Systems Failure framework they were selected among stakeholders related to demand, biogas companies and farmers, knowledge institutes, and related third parties (Klein Woolthuis et al., 2005).

As a result, the method of sampling for these individuals to represent the biogas sector in the region followed a purposive sampling method, to ensure representation from diverse backgrounds and experiences. Purposeful sampling is a widely used qualitative research technique for the identification and selection of information-rich cases and involves identifying and selecting individuals especially knowledgeable about a phenomenon of interest (Palinkas et al., 2015).

4.4.2.1.1 Participants

Given the researcher's limited connections with any of the stakeholders in the area, multiple ways of contacting and reaching the stakeholders were implemented. Initially, an extensive market analysis regarding the Greek biogas industry and the Thessaly region was conducted to identify the key stakeholders, related actors, and the different types of participants that could contribute with their views to the interview process.

As a result of this process, some initial contacts were found and contacted via email or phone. Through this process, different types of stakeholders and other stakeholders were contacted. The interactions with each group and the reasons for including them in this study are presented below:

- **Companies**: Incorporating the perspectives and views of Biogas Companies in the region of Thessaly was important for this study as this group constitutes the main producers of biogas. Biogas production employees and plant managers were an important group of stakeholders in this study as they are the main individuals who represent the interests of the biogas production industry and understand the main technical and production issues in the industry. Furthermore, their relations with multiple different stakeholders in the industry would provide a structured overview of the current actors involved in the region of Thessaly and the possible issues between them. To approach these stakeholders multiple emails and phone calls were utilized to establish a connection and agree to participate in the study. In total 3 company representatives agreed to participate and also share data related to the region and its biogas production characteristics.
- **Third Parties**: These parties such as Biogas Associations, industry experts, biogas investors, and in general parties indirectly involved with the biogas production and technology diffusion in the area were an important group that could contribute to the data collection process providing an overall image of the system. Taking into account the limited organization characteristics in the area and the biogas industry in Greece in general, little information was available related to these actors.

  Finally, 2 of the contacted stakeholders agreed to participate in the study and comprised of a Funding Organization and a Biogas Entrepreneur. The perspectives of the funding organization representative were considered essential to identify the financing of innovation actions in the area and the innovation output of Greece and Thessaly whereas the biogas entrepreneur could provide the challenges of doing business in the biogas industry and information about the codes of conduct and the future of biogas in the region.

  The influence of the Hellenic Biogas Association is noticeable in the country as the association represents the interests of a large number of biogas producers. However, despite the active role of the association in the country a response was not received as the complex bureaucratic mechanisms of the association slowed down the participation in the study.

- **Knowledge Institutions**: Through the perspectives of Research Organizatons it was important to identify knowledge development activities and R&D programs that might contribute to the TIS related to Biogas Technology. Additionally, these academia members could provide important input regarding the challenges of conducting research in the Greek Biogas Innovation System and their perspectives on the region.

Numerous researchers in the region of Thessaly and Greece were contacted and one research organization participated in the final interviews to identify the knowledge diffusion capabilities and level of innovation output of the area.

- **Citizen Groups / Other Stakeholders**: Incorporating the participatory design approach and examining the inclusion of other stakeholders and communities in the production of the region required the perspectives and views of these groups indirectly related to biogas.

  Taking into account the recent catastrophic events of the Daniel storm and the destruction of many civilian houses in the region, the views of citizens and their perspectives on their inclusion into an energy transition system that could help them guarantee energy security were important for this study. As a result, one participant, a victim of these catastrophic floods was interviewed to take into account the needs of this stakeholder group in the system requirements.

  Additionally, the role of **energy communities** in the region is related to combined actions with various NGOs, community members, and citizens and an interview with a representative from a local energy community would be important to understand the actions to include, educate, and help members of the local communities in energy security and energy transition. As a result, one representative from an energy community was successfully approached to participate and share their views on the community's biogas actions and the current situation of the region.

- **Farmers / Farmer Cooperatives & Biomass Suppliers**: This important stakeholder group is directly involved with biogas production in the region as it has been stated that existing regulations in Greece forbid the uncontrolled disposal of agricultural and animal residues in the environment.

  As a result, it would be important to take into account the farmer's opinions and views on the waste management practices from their side, their actions in the biogas system, and possible challenges faced.

  Many different farmers and farmer organizations were approached, however, due to the slow responses and limited interest only one Biomass Supplier was able to participate. At the same time due to the farmer’s low educational level (Panoutsou, 2008), a phenomenon widely observed in the Greek countryside, many difficulties were noticed in the efforts to approach them via email.

- **Natural Gas Distributors**: During the interview process the use of biomethane and its potential to be injected was mentioned in numerous cases. This created a need to interview also representatives from the Natural Gas sector in order to note their perspectives regarding biomethane utilization and the existing actions towards the connection of the two sectors.

As a result, one Natural Gas expert was included as a participant in the interviews providing valuable insights on the natural gas networks, biomethane specifications, and recommended actions to strengthen community inclusion.

In total out of the 30 individuals, organizations, institutions, community representatives and companies contacted the final number of positive respondents interested in sharing their view for this Master Thesis was 10.

4.4.2.1.2 Stakeholder Documentation

The actions to access and agree to an interview with all the different individuals lasted approximately one month while a comprehensive list of names, roles, contact information, and actions diary was created in order to keep track of the process.

An example of the reporting process can be found in Appendix A: Participant Documentation after the participant names and contact information have been anonymized.

The final list of participants is presented in Table 4 below:

Number	Participants	Date of Interview
Companies		
1	Biogas Company Expert A	**19/04/2024**
2	Biogas Company Expert B	**24/04/2024**
3	Biogas Company Expert C	**29/04/2024**
Research Institutes		
4	Research Organization	**24/04/2024**
Energy Communities		
5	Energy Community	**19/04/2024**
Third Parties		
6	Funding Organization	**22/04/2024**
7	Biogas Entrepreneur	**16/04/2024**
Inclusion of indirect stakeholders		
8	Flood Victim Member of Thessaly	**06/05/2024**
Natural Gas Industry		
9	Natural Gas Expert	**04/05/2024**
Biomass and Waste Supply		
10	Biomass Supplier	**10/05/2024**

Table 4 Participants Table

4.4.2.2 Setting

To reduce the resource-intensive character of the interviews, virtual interviews were incorporated, optimizing the efficiency of the study and data collection. Besides the participants and the facilitator of the interview, there was no other individual present.

The interviews were conducted using the Microsoft Teams software providing an easy-to-use platform including a recording tool that was utilized in order to transcript the collected data.

As all the participants were from Greece all the interviews were conducted in the Greek language to help them express their views without limitations of the language factor. The interviews were later translated into English.

4.4.2.3 Data Collection and Interview Material Structuring

The interview material was constructed by the researcher. The material for the interview was based on the exploratory character of the interviews and included open-ended questions to receive detailed responses.

The first interview format can be seen in Appendix B: First Interview Format provided in Greek and English and a detailed description of the method it was written. After the first interview, the format was chosen to be changed in order to improve the flow of the interview and help participants understand the questions better. The revised format is presented in Appendix B: Revised Interview Format including the description of how it was constructed based on the feedback from the first interviews.

For interviewing the Thessaly Flood Victim it was decided to change the interview format and additionally include results from the findings of the previous interviews in order to collect the views of the specific participant regarding certain findings. This specific format is presented in Appendix B: Flood Victim Interview Format both in Greek and English language including the method it was structured.

To reduce possible researcher fatigue which could affect the researcher (American Psychological Association, 2018), the interviews were performed in the course of four weeks also in respect to the time constraints of the research and the availability of the participants.

With the consent of the participants, the interviews were recorded. Furthermore, the interviews were aimed at having a duration of 1 hour. A summary of the individual interviews was handed out to each participant to provide comments and feedback that could later be included in the final analysis.

4.4.2.4 Validation

In order to validate the information collected several methods were developed during the interview process.

Due to the large number of of information collected during the interviews the interviewer aimed to summarize and confirm the important points of the participant's answers to confirm information and collect further comments. This ensured that the information collected aligned with the participant's views and assisted in validating the data collected.

Additionally, summaries of the interview content were shared with the participants following the analysis to provide additional feedback. Although limited feedback was received the comments were thoroughly considered and included in the analysis.

Lastly, open contact after the course of the interviews was preserved in order for the participants to mention additional views that might have not been included in the interviews. This resulted in additional information collected after the course of each interview and additional comments were considered in the analysis.

These methods helped verify the collected information and enhance the credibility of the results. The validation process supported the data and provided substantiated conclusions based on the collected information.

4.4.3 Data Analysis and Findings

The analysis of the data was conducted by the researcher and author of the Master Thesis. The analysis part used qualitative coding, the process that allows collected data to be gathered, classified, and thematically organized, creating a structured foundation for finding themes and patterns (Williams & Moser, 2019).

To analyse the collected data a deductive approach was initially applied. As a result, based on the theoretical basis, predefined themes were created based on the research objectives. At the same time, the analysis relied also on codes and sub-themes that emerged deductively and inductively during the interviews.

For instance, in an effort to identify the characteristics of the Greek Biogas Innovation System, the codes followed an inductive approach aiming to map the Innovation System from the perspective of the stakeholders while sub-themes were predetermined and aligned with the objective of the research.

In a similar way, on understanding the challenges observed from that innovation system the analysis followed a deductive approach as the themes were predetermined and aligned with the objective of the research and the structure of the interviews.

This analysis process had an ultimate result of **124** codes categorized into **12** sub-themes under **3** main themes. The Themes were aligned deductively with the determined research objectives while codes were inductively created during the analysis process. The followed framework for the thematic analysis is presented below in Figure 3 Thematic Analysis Framework:

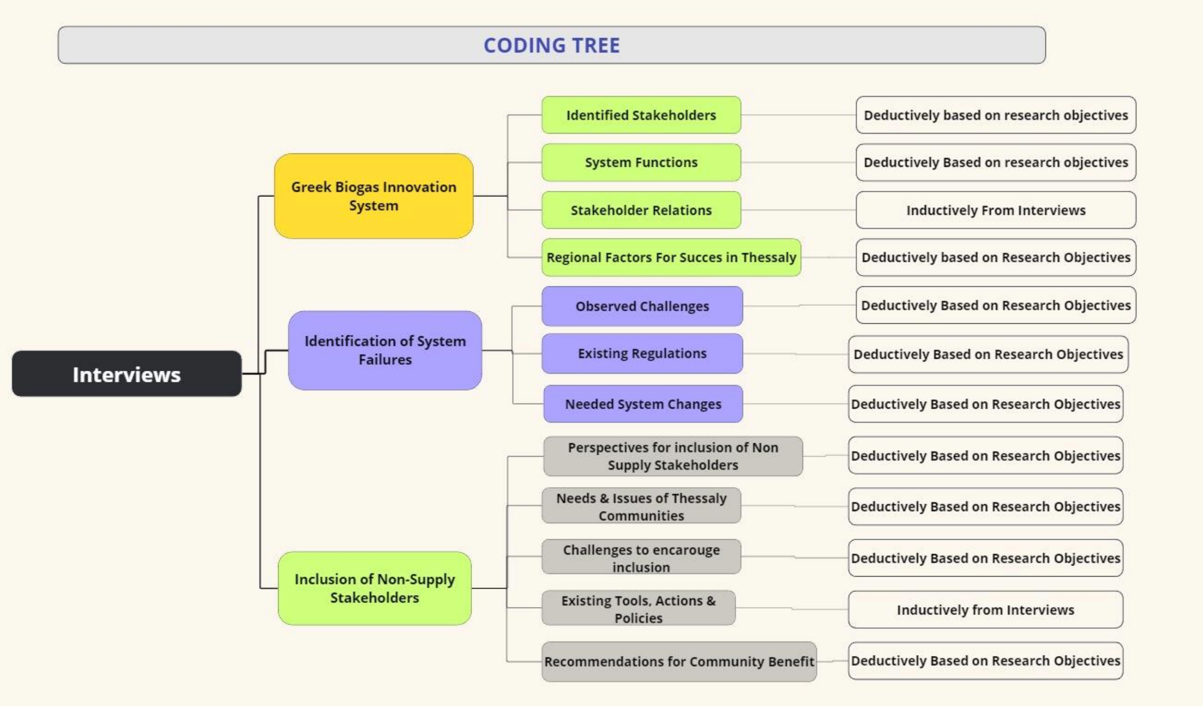

Figure 3 Thematic Analysis Framework

4.4.3.1 Reporting

4.4.3.1.1 Summarized Interview Insights

To provide an engaging representation of the results, selected participant quotations linked to specific codes were included in a paraphrased and summarized form and integrated into the main text of the results instead of using direct participant quotes. Roles and titles were assigned to each participant to maintain participant anonymity and used in any necessary references in blue color.

All data presented in this study aligned with the findings from the interviews, providing supporting evidence for the identified themes and enhancing the overall understanding of the research topic. The results were organized around the main themes identified during the analysis. Within each theme, various findings were presented, organized, and synthesized, which improved the clarity of the key themes and aided in interpreting the research results.

4.4.3.1.2 Results table format

The identified sub-themes were additionally organized in a table format where corresponding codes aligned with the participants who expanded on them. The results in this format are presented in Results chapter including detailed instructions on how to read the tables.

4.4.3.1.3 Thematic Analysis Reporting

It is also valuable to mention methods applied during the analysis for efficiency and consistency. Figures related to the thematic analysis are presented in Appendix A: Thematic Analysis Method Reporting.

Using the above methods, this thesis aimed to strengthen the study's credibility by accurately reflecting the participants' perspectives and guaranteeing the reproducibility of the findings.

5 Results

In this chapter, the interview results are presented in a structured way including the perspectives, views, and information gathered during the interview process. The presentation of the results follows the thematic analysis with the results presented in a table format and in text in this chapter.

How to read the tables: The tables presented in this chapter include results of the thematic analysis organized in such a way that (X) links the codes and the stakeholders that mentioned them and expanded on the topic. The tables also include key aspects mentioned by the participants.

The structure of this chapter follows the analysis of the interview's main themes and the research objectives. While the results are presented certain codes also indicate the frequency that they were mentioned, representing their importance to the participants.

Initially, the results of the **Greek Biogas Innovation System** mapping are presented. This theme provides an understanding of the existing system around biogas technology, the main active stakeholders involved, the relations between them, and certain system functions that were identified. The identification of the innovation system represents the innovation system at a national level however, certain characteristics were observed entirely for the Thessaly region.

Following, the **System Imperfections and Needed Changes** include all the observed challenges that were identified by the interview participants during the interview process, the existing policies, and the changes required in the system around biogas production and innovation.

Finally, the perspectives of the interviewees on the **Inclusion of Non-Supply Stakeholders** set the basis for understanding the needs, issues, and challenges of the Thessaly communities while recommending certain actions that could encourage support for the locals devastated by the recent storm through biogas.

5.1 Greek Biogas Innovation System

The first subject of the interview discussions and an important part of understanding the environment around biogas in Greece and in particular in Thessaly was centered around the existence of different stakeholders and system functions related to biogas technology. As all of the interview participants had either a direct relation to biogas or it was a part of their actions, all of them were able to identify and expand on at least one of the identified codes, providing information on the current biogas system.

5.1.1 Identification of Stakeholders

Through the interview process, numerous different stakeholders were identified and analyzed by the participants. Initially, participants were able to describe and identify directly involved actors that they have relations with, however through the interview process it was possible to notice additional stakeholders that are involved in the biogas system. The results in a table format and in text are presented below in Table 5.

Stakeholders Identified	Biogas Entrepreneur	Energy Community	Funding Organization	Thessaly Biogas Company A	Thessaly Biogas Company B	Thessaly Biogas Company C	Natural Gas Expert	Research Organization	Biomass Supplier	Flood Victim of Thessaly
Investment Organizations	X			X	European Funds & Banks	X				
Research Funding Organizations			X							
Biogass Suppliers	Livestock and Agriculture Farmers	X		X	X	X		X	X	
Municipal Authorities		X		X	Permitting	X	X	X		
Research Institutes	X	X	X	X	X	X				
Biogas Companies	X	X		X	X	X	X	X	X	
Natural Gas Companies	Potential Stakeholders			X	X		X			
Government Bodies	Policymakers and Direction of the Industry		X	Ministry of Energy	X	X	X	X		
Biogass Association	Support of Biogas Companies interests	X		X	X	X	X			
European Union		Horizon Programmes	X	X	X					
NGO's		X								
Biomass Association		Interests of Biomass Producers								
Energy Communities	X	X						X		
Construction Companies				X						
Communities and Locals	X	X		X	X		X			X
Biomass Transporters						X			X	

Table 5 Results: Greek Biogas Innovation System Stakeholders Identified

Most of the participants were able to identify the role of **Biogas Companies** (8 out of 10 participants). Biogas plants are mainly supported by two types of investors, land use managers already involved in agricultural and farming activities who want to utilize their organic wastes and independent investors who also have other activities in RES (Biogas Entrepreneur, Research Organization). In particular independent investors are usually familiar with the technology and the industry and are interested in the profitability of such units (usually close to a 15% profit margin and a 10-year payback period) (Thessaly Biogas Company A).

Biomass Suppliers (7 out of 10 participants) were also a stakeholder group identified in the system. They are usually agricultural and livestock farms that supply residues to the Biogas Companies (Energy Community) or food processing industries such as olive oil mills (Biomass Supplier).

Municipal Authorities (6 out of 10 participants) and **Government Bodies** (7 out of 10 participants) were mentioned as the main bodies related to the permitting process of a biogas plant and the required documents (Thessaly Biogas Company A, Thessaly Biogas Company B, Thessaly Biogas Company C), their role in providing incentives directing the biogas technology expansion in the area (Biogas Entrepreneur) while there are cases where municipality waste collection projects for biogas processing are involving the municipal authorities (Energy Community).

Research Institutes (6 out of 10 participants) are involved in the system through the development of knowledge around biogas while they organize joint actions with companies for pilot scale research (Thessaly Biogas Company B) or provide data to government bodies for the monitoring of the biogas system (Research Organization). **EU** is also involved in the system through the funding of different innovative programs (HORIZON) (Thessaly Biogas Company B, Energy Community) while research projects are also funded to a certain percentage by **Research Funding Organizations** (Funding Organization).

Commercial Projects are mainly funded by **Investment Organizations** and in most of the cases involve Banks (Thessaly Biogas Company A, Thessaly Biogas Company C) or European Funds (Thessaly Biogas Company B).

Biogas Association's role was also mentioned during the interviews by 6 participants, and its main objective is the representation of the interests of the biogas producers in the ministries and the policymakers (Thessaly Biogas Company B).

Additionally, the role of supplementary stakeholders was mentioned such as **NGOs** (1 out of 10 participants), **Energy Communities** with recent involvement (3 out of 10), **Construction Companies** (1 out of 10), **Biomass Transporters** (2 out of 10), **Natural Gas Companies** (4 out of 10), **Biomass Association** (1 out of 10).

Communities and Locals are in many cases indirectly involved as residents of areas where biogas plants are located in the system and were recognized by 6 participants.

5.1.2 System Functions

Through the interview questions, the participants were able to identify specific functions in the Greek Biogas Innovation System that relate to the TIS functions. As a result, the different participants recognized and expanded on the existence of these functions either from their direct experience or their knowledge of the industry. The results in a table format (Table 6) and in text are presented below.

System Functions	Biogas Entrepreneur	Energy Community	Funding Organization	Thessaly Biogas Company A	Thessaly Biogas Company B	Thessaly Biogas Company C	Natural Gas Expert	Research Organization	Biomass Supplier	Flood Victim of Thessaly
Commercial Projects and Initiatives	X	X			X		X	X		
Knowledge Development Actions			X	X	Academia & Companies Cooperations	X		X		
Knowledge Diffusion Indicators	Events (producers and academia)	Workshops, Platforms	Number of Publications	Conferences	X	X				
Innovation Direction		Farmer Regulations		Biomethane Expectatio	X					
Market Formation Actions	FiTs			No investment funding, No Tax Reduction	X	X				
Mobilization of Resources	X	Grants,LEADER Programms, Banks,	X	X	Funding	X	Existing Gas Infrustructure, Natural Gas Experts,	X	Periodic waste production	
Legitimacy Formation	Interest Groups, Biogas Associations	X		X	X	X				

Table 6 Results: Greek Biogas Innovation System Functions

Entrepreneurial activities (5 out of 10 participants): The existence of commercial projects in Greece specifically in the region of Thessaly is evident through the information provided by the participants. Many of the developed or scheduled projects are in close proximity to each other (Thessaly Biogas Company C), are based on the existing technological knowledge mainly from European Construction Companies (Thessaly Biogas Company B) and only a few innovative projects exist (Thessaly Biogas Company A). There are at this point only a few discussions regarding biomethane projects in small areas for pilot scale testing that have not yet been implemented (Natural Gas Expert). In the past one project has, without success, developed hydrogen production units near the biogas plant while only one project in Greece, and not in the region of Thessaly, applies the biogas injection to the natural gas grid (Research Organization).

Knowledge Development Actions (5 out of 10): Interview participants were able to identify and analyze different knowledge development actions and their involvement in different projects in the region of Thessaly. The National Technical University of Athens and the University of Thessaly are involved in research on biogas technology, digestate management, and biomethane technology (Thessaly Biogas Company B, Thessaly Biogas Company C). Overall there is a large number of projects related to R&D, especially at low TRL stages and wide diffusion of research publications to high impact factor international journals (Funding Organization).

Knowledge Diffusion (6 out of 10): Different indicators of knowledge diffusion were mentioned during the interview process. There are **workshops** in coordination with EU programs and Energy Communities (Energy Community), **conferences, and events** organized by the Biogas Association, Companies, and Academia (Biogas Entrepreneur, Thessaly Biogas Company A, Thessaly Biogas Company B, Thessaly Biogas Company C) while there are also European Programs such as Project "ALPHA" aimed to provide to interested parties the needed information and techno-economic knowledge for the development of biogas units (Energy Community). At the same time, there are also informal connections for knowledge sharing between companies from different regions, due to the low competition between the parties (Thessaly Biogas Company C).

Guidance of the Search (3 out of 10): Certain activities on innovation direction were identified such as the institutional framework for farming and organic residues which enforced the processing of these wastes by biogas plants and increased productivity in recent years raising expectations (Energy Community). Additionally, biomethane technology is constantly displayed by articles, news, and events as an upcoming solution for biogas producers increasing the expectations for a connection between natural gas distributors and the biogas sector (Thessaly Biogas Company A, Thessaly Biogas Company B).

Market Formation Actions (4 out of 10): Actions related to market formation are mainly related to the existent feed-in tariffs that provide a certain period of stable price for the produced electricity at 180-220 €/MWh (Biogas Entrepreneur). Due to the FiTs there are however no Tax reductions for biogas companies and no government funding as the tariff is mainly translated as a support to the technology support (Thessaly Biogas Company A, Thessaly Biogas Company B, Thessaly Biogas Company C). It is additionally expected that biomethane regulation will be able to open the market and thus this regulation, once is ready, will by itself assist the expansion of the industry and form a strong market on biogas production (Biogas Entrepreneur, Thessaly Biogas Company A).

Mobilization of Resources (9 out of 10): This category was the one that mainly interested the majority of the stakeholders. The results revolve around four certain indicators: Experts on biogas, existing infrastructure, financial tools, and the availability of resources for biogas production.

As the market is considered still small there are no experts or educational tools such as MSc programs related to biogas production (Biogas Entrepreneur) and the majority of biogas engineers have hands-on experience in the field through years of practice (Thessaly Biogas Company A, Thessaly Biogas Company B).

Government actions such as the program "Ereuno Kenotomo" and European Union funding are also providing financial resources for companies, and researchers to develop biogas research projects (Biogas Entrepreneur, Funding Organization, Thessaly Biogas Company A).

In terms of financial tools, banks are familiar with biogas projects and positive in providing debt financing (Thessaly Bioags Company A, Thessaly Biogas Company C) while there is also the ability to use LEADER programs for project financing or cooperative banks of the region (Energy Community).

The regions of Thessaly and many other regions in Greece have very high residue resources available for biogas production (Thessaly Biogas Company A, Energy Community) with large quantities of residues such as olive oil wastes following the agriculture period circles (Biomass Supplier) however the issues with the supply of the wastes will be further expanded in the Observed Challenges chapter.

The infrastructure and especially the existing capabilities of the electricity grid in Thessaly but also in Greece in general has limited capacity however all areas are connected to the grid. Additionally, the infrastructure for biomethane distribution is existent in the region and in Greece in general (Biogas Entrepreneur). Natural Gas distributing companies are ready to handle the future biomethane production, in terms of both infrastructure and human resources expertise (Natural Gas Expert).

Legitimacy Formation (5 out of 10): The interest groups of RES companies related to electricity production are close to the interests of the biogas industry as the demand for upgrades in the electricity grid is a common ground for all the renewable energy producers (Biogas Entrepreneur). Moreover, the Biogas Association is currently the main interest group for biogas as it represents the interests of the stakeholders involved (Energy Community, Thessaly Biogas Company A, Thessaly Biogas Company B, Thessaly Biogas Company C).

5.1.3 Stakeholder Relations

Throughout the analysis process, it was possible to identify connections in the relations between certain stakeholders in the Greek Biogas Innovation System. The results in a table format (Table 7) and in text are presented below.

Stakeholder Relations	Biogas Entrepreneur	Energy Community	Funding Organization	Thessaly Biogas Company A	Thessaly Biogas Company B	Thessaly Biogas Company C	Natural Gas Expert	Research Organization	Biomass Supplier	Flood Victim of Thessaly
Biomass Suppliers with Biogas Companies	Shareholders in many projects, long term contracts	x							Competitve in certain organic wastes	
Biodiesel Producers with Biogas Companies	Antagonistic Feedstock Supply									
PV, Wind Turbines with Biogas Companies	x									
Biogas and Biomass Associations Cooperation		x								
Energy Community with Biogas Companies		x								
Energy Community with Farmers		Economic Relations and Members								
Energy Community with Academia		x								
Research Funding Organizations with Research Laboratories			x							
Biogas Companies with Natural Gas Distributors				x						
Relations Between Companies				x		Close relations in proximity				
Biogas Companies with Academia	x			x	x					
Biogas Association with Biogas Companies	x			x	x	x				
Biogas Association with Academia					x	x				

Table 7 Results: Greek Biogas Innovation System Stakeholder Relations

These relations between the stakeholders are presented below:

Biogas Companies relations with:

- **Biomass Suppliers**: With many of the biogas suppliers cooperate as shareholders and with long-term supply contracts (Biogas Entrepreneur) or competitive relations for the same organic waste resources (Biomass Supplier).
- **Biodiesel Producers**: In many cases, Biodiesel Producers are antagonistic for biomass supply to biogas companies as they have common resources (Biogas Entrepreneur).
- **PV and Wind Turbines**: Due to the existent limitations of the electricity grid capacity Biogas Companies compete for permits with the PV and Wind Turbine industry (Biogas Entrepreneur).
- **Biogas Association**: The association apart from its purpose to support the interests of the producers also provides a networking space for companies to cooperate and form relations (Thessaly Biogas Company B) even though it does not include all the companies producing biogas (Thessaly Biogas Company A).
- **Energy Communities**: There are existing relations with biogas companies in order to support energy communities on knowledge and experience transfer for biogas production (Energy Community).
- **Other Biogas Companies**: There are existent informal positive relations between companies regarding knowledge transfer and assistance (Thessaly Biogas Company A), however in close proximity the relations are more competitive than between companies that don't compete for the same resources (Thessaly Biogas Company C).

- **Natural Gas Distributors**: Currently there are informal commitments such as M.O.Us (Memorandum of Understanding) signed by biogas producers and natural gas parties regarding future biomethane production (Thessaly Biogas Company A).
- **Academia & Research Institutes**: There are many connections between companies and research laboratories, especially in the European Union Horizon projects (Thessaly Biogas Company A). There are, additionally, common projects in the region of Thessaly focused on biomethane production and digestate management (Thessaly Biogas Company B, Thessaly Biogas Company C).

Biogass Association relations with:

- **Biomass Association**: The two associations interact through common actions and provide a network for biogas producers and biomass suppliers to connect and share interests under a common umbrella (Energy Community).
- **Academia**: Joint actions between universities and the biogas association show the close relations between the stakeholders and the mutual support in organizing information actions and events (Thessaly Biogas Company B).

Energy Communities relations with:

- **Farmers and Biomass Suppliers**: Many farmers and biomass suppliers are members of energy communities, while there are also economic relations between the stakeholders for biomass supply and community support (Energy Community).
- **Academia**: Certain cooperative actions such as joint projects for research purposes are developed between Universities and Energy Communities (Energy Community).

Research Funding Organizations' connections with **Academia** are strictly typical for the purpose of research funding (Funding Organization).

Overall, the most common relations identified were between Biomass Suppliers and Biogas Companies mentioned by 3 out of 10 participants, between Biogas Companies and Academia, mentioned by 3 out of 10 participants and between Biogas Association and Biogas Companies as it was mentioned by 4 out of 10 participants.

5.1.4 Regional Factors of Success in Thessaly

Regarding the regional factors that supported the success of the Thessaly region in the early establishment of biogas units 6 of the 10 participants mentioned at least one reason. The results in a table format (Table 8) and in text are presented below.

Regional Factors For Succes in Thessaly	Biogas Entrepreneur	Energy Community	Funding Organization	Thessaly Biogas Company A	Thessaly Biogas Company B	Thessaly Biogas Company C	Natural Gas Expert	Research Organization	Biomass Supplier	Flood Victim of Thessaly
Availability of Farming Residues	X	X		X	X	X			X	
Investment Decisions	X									
Location		Close Proximity of Resources		Large Plain	X	X				
Energy Security		X								
Institutional Framework		X								
Initialy Available Electricity Network				X					X	

Table 8 Results: Greek Biogas Innovation System Drivers for Adoption in Thessaly

The main factor identified was the **Availability of Farming Residues** as all of the 6 participants identified this driver. The region has the potential to utilize different agricultural wastes (Biogas Entrepreneur), and has a large abundance of resources available (Energy Community, Thessaly Biogas Company B) as the agricultural activities in the area produce large amounts of biomass wastes that provide opportunities to the potential biogas producers (Thessaly Biogas Company A).

Supporting to the previous driver is the **Location** of the region (mentioned by 4 participants) as Thessaly has the largest plain in the Balkans (the Thessaly Plain) (Thessaly Biogas Company B) allowing many biogas producers to take advantage of the residues in close proximity to some of the farming activities (Energy Community). Additionally, other factors such as **Investment Decisions** based on personal interests (Biogas Entrepreneur), the need for **Energy Security**, the incentives provided by the **institutional framework** (Energy Community), and the **initially available capacity of the electricity network** (Thessaly Biogas Company A, Biomass Supplier) helped the region expand in the biogas production sector.

5.2 System Problems and Needed Changes

During the interview process, the participants were able to identify numerous existing challenges and problems of the Greek Biogas Innovation System. These challenges as presented below are related to the system imperfections, hindering the success of biogas diffusion in Thessaly. Additionally, existing regulations were mentioned and discused during the interview process. After the identification of the related to biogas problems the needed changes in regulations were also mentioned providing recommendations on actions that should be taken for the benefit of all the involved stakeholders.

5.2.1 Observed Challenges

The observed problems in the biogas innovation system were initially identified and further categorized into categories of problems. The results in a table format (Table 9) and in text are presented below.

Observed Challenges	Biogas Entrepreneur	Energy Community	Funding Organization	Thessaly Biogas Company A	Thessaly Biogas Company B	Thessaly Biogas Company C	Natural Gas Expert	Research Organization	Biomass Supplier	Flood Victim of Thessaly
Biomass Market Price	X				Pultry Farm Wastes	X			X	
Availability of Biomass/Feedstock	No Organized Collection	X		X	X			X	X	
Permitting Challenges	X	X		X	X					
Digestate By-Product Management	Logistic Costs				X					
Farmer Waste Management	X	X		X	X	X				
Difficult to enter the industry	X									
Limited Industry Information	X					X				
Capacity of Electricity Grid	"Limited"	X		X	X	X	X	X	X	
Road Infrustructure				X		X				
No Success Cases		X								
No observed Benefits		X		X						
Absence of Experts		X				X				
Problems in Cooperation		X								
Limited Financial Resources			X							
Small Number of Biogas Plants				X						
Media Image of Bioags				X						
Regulation Gaps				X		X			X	
Hostility from Locals				X				X		
Slow Funding Process					X					
Low Research Output	X				X					
Energy Prices						X				
Absence of Big Players							X			
Strong Competition						X				
Effects of Daniel Storm		X		X						

Table 9 Results: Greek Biogas Innovation System Observed Challenges

These problems are related to the existing:

Infrastructure: Problems in the system related to the existing physical and technology infrastructure were characterized as mainly problems related to:

- **Capacity of Electricity Grid**: One of the main challenges identified by 8 of the 10 participants was the current capacity of the electricity grid to handle the produced electricity. Defined as saturated or limited, the electricity grid is not able to absorb further load (Biogas Entrepreneur, Thessaly Biogas Company B) or large electricity production by the biogas CHP units (Energy Community). The electricity infrastructure networks are old and outdated with limited current actions of upgrades while this issue creates a major obstacle on the availability of biogas plant construction permits (Thessaly Biogas Company A, Biomass Supplier). This issue is, in general, a large problem hindering the Green transformation of the country observed in also other RES in Greece and Thessaly specifically with many areas of the country unable to introduce any additional renewable energy technologies (Natural Gas Expert, Thessaly Biogas Company A). Regarding the biogas production there are cases that this problem has forced the biogas producers to shut down their CHP unit in certain hours or provide daily reports on the Public Power Corporation for the expected electricity production of the next day (Thessaly Biogas Company C).
- **Road Infrastructure**: The problematic conditions of the road infustructre have been mentioned by 2 participants. Many of the road networks in the region are in bad condition with biogas companies taking action to construct their own roads if needed (Thessaly Biogas Company C).
- **Low Research Output**: A problem related to the current ability of research facilities to provide support in biogas innovation has also been mentioned. As there are research

programs related to biogas innovation they are at the moment in experimental or small scare stages, with companies not being able to benefit from the innovative solutions available (Thessaly Biogas Company B).

Institutions: The bottlenecks of institutional mechanisms are related to:

- **Permitting**: As a related problem to the capacity of the electricity grid, the permitting process was mentioned by 4 out of the 10 participants as an issue. There are currently limited permits available in the region of Thessaly and none in many other areas for electricity production from biogas.(Biogas Entrepreneur). Additionally apart from this challenge the institutional framework requirements and the different governmental bodies required to sign for a permit to be given, create a difficult situation (Energy Community) with bureaucratic complexity (Thessaly Biogas Company A) and slow document processing time by each government and municipal authority (Thessaly Biogas Company B).
- **Farmer Waste Management**: A problem identified during the interviews that has a direct relation to the supply of biomass is the institutional framework regarding waste management from the side of the farmers. Even though the regulation exists forcing the producers of biomass to provide it to processing units such as biogas plants on many occasions farmers are not obligated to follow waste management plans or monitored, resulting in the disposal of large quantities of organic waste in the environment (Biogas Entrepreneur, Energy Community). The case of livestock farmers disposing of their wastes uncontrollably in the environment has numerous environmental hazards (Thessaly Biogas Company A). At the same time, it limits the expansion of biogas plants as in case the regulation was put in practice this would provide additional feedstock for biogas plants to secure stable biogas production (Thessaly Biogas Company C). For the purpose of the regulation monitoring the existent electronic database of wastes is the only tool for reporting the produced biomass wastes however many of the small farming businesses are not registered (Thessaly Biogas Company B).
- **Regulation Gaps**: Many regulation gaps were identified such as bottlenecks in operational documents. Certain wastes are in question of whether they are still considered a food source or a waste resulting in bureaucratic issues (Thessaly Biogas Company A) with no clear definitions of the permitted wastes for biogas production. An example of such a case could be the competition between the olive processing plants and the biogas companies, as the secondary by-product of the olive core contains a certain amount of olive oil while also provides a good source for biogas production (Biomass Supplier). In addition, the rules biogas companies are forced to comply with are in cases in question by the same authorities that construct them resulting in confusion among the stakeholders (Thessaly Biogas Company C).
- **Slow Funding Process**: Another issue mentioned refers to the slow processing times in the bank approval process. As banks are not fast in financing projects this can result in increased costs for many biogas construction projects. The costs of materials can change during the construction time of a project and procurement costs can be affected in case the project funding is not parallel to the project implementation schedule (Thessaly Biogas Company B).

Interactions: During the interviews, issues related to the interactions between stakeholders were highlighted as significant barriers to the biogas technology.

- **Difficult to enter the industry:** Regarding the connections between biogas producers, the Biogas Association represents the interests of its members with strong relations between the existing members. This makes it difficult for new entrants such as new biogas plant investors to enter the industry (Biogas Entrepreneur).
- **Problems in Cooperation:** Investments such as the construction and operation of a biogas plant require the cooperation of many different actors, the creation of supply chains and differ from other RES such as PVs and Wind Turbines that do not require additional attention. The essence of cooperation has taken a negative image due to past failures in cooperative farming projects and as a result there is an issue nowadays to to make people work together (Energy Community).
- **Media Image of Biogas:** One of the existing problems related to the expansion of biogas technology and additionally related to its acceptance by the public is the negative image of biogas projects. It is often that media do not present a positive image of biogas plants and tend to broadcast only the negative news such as accidents that occur or plant malfunctions. This by itself does not create a positive environment for the technology (Thessaly Biogas Company A).
- **Hostility from locals:** The local communities and some municipal authorities are often negative and hostile against the biogas companies. Some municipal members with business activities oversee the possibility of collaborating with biogas companies and instead aim to hinder their expansion (Thessaly Biogas Company A). At the same time, locals are usually hesitant to accept biogas plants in their region mainly due to factors such as the unpleasant odors of these plants, political reasons, business interests, and also existing cases of environmental violations related to the operation of some biogas plants (Research Institute). The above issues are creating a hostile environment between biogas companies and local communities in many areas, making it difficult for biogas projects to be supported.
- **Strong Competition**: An existing problem mentioned is related to the strong competition in close proximity between the biogas companies. As this competition is mostly related to the supply of resources for biogas production there is limited transfer of knowledge between the companies which also hinders the expansion of the technology and the rise in the number of producers (Thessaly Biogas Company C).

Capabilities: Challenges for companies to secure resources or access information were also identified during the interviews. These challenges relate to:

- **Availability of Biomass/Feedstock:** One of the most frequent challenges among the stakeholders and especially the biogas producers in the biogas industry is related to the resource deficiencies observed in the system. This problem is linked to many other issues in the innovation system and has been mentioned by 6 out of the 10 participants as a big problem in the industry. Even though Thessaly is located in a resource-rich area the biogas plants face problems related to the availability of the needed feedstock for biogas production. As there is no organized body to secure an organized allocation of resources or centralize the biomass gathering (Biogas Entrepreneur, Energy Community) each plant has to independently communicate with all the biomass suppliers and maintain relations with 50 or 100 different suppliers (Thessaly Biogas Company B). The absence of an organized collection creates also high logistics costs for the companies with these costs eventually constituting the largest part of the operational costs of a plant (Thessaly Biogas Company A, Thessaly Biogas Company B). The availability issues of biomass also create a problem to the quality of the produced biogas as the changes in the mix of substrates and the unstable supply of feedstock constantly change the operational specifications of production and the biological characteristics of the bioreactors (Research Organization, Thessaly Biogas Company B).

- **Limited Industry Information:** The interview participants have also pointed out the issue of limited information. Companies and government bodies are unable to have a clear image on the available resources in many regions and there is little transfer of knowledge from the side of the farmers (Biogas Entrepreneur). Additionally, there is limited information in the system regarding the quality standards of biomass (Thessaly Biogas Company C).
- **Absence of Experts:** The absence of experts is a problem, especially for companies or communities that want to enter the biogas system (Energy Communities). Companies face the absence of employees with experience in biogas production and it is difficult to find skilled professionals for maintenance and improvements operations. Often people with experience in the field have limited availability and are expensive (Thessaly Biogas Company C).
- **Limited Financial Resources**: The existence of many different projects for R&D requires the corresponding funding resources that are not available for many innovative biogas projects with technological potential (Funding Organization).

Market: Problems with the existing market and its expansion or the interrelation with other markets such as the electricity market are creating problems for the biogas technology expansion:

- **Biomass Market Price**: The problem that biomass has started to create a market and has price fluctuations in the biogas innovation system has been mentioned by 4 participants during the interview process. Due to the competition between companies and the limited access to resources biomass suppliers have started to respond to the demand for certain residues and put a price on many of the wastes that are normally provided for free to the biogas producers (Biogas Entrepreneur, Thessaly Biogas Company C). An example of this issue relates to the wastes from poultry farming which are considered a rich source for biogas production and have a high demand (Thessaly Biogas Company B, Biomass Supplier). This issue raises the production costs for biogas while the logistics costs also contribute to the high costs to acquire biomass.
- **No Success Cases**: Additionally there are no success cases in the market to influence also others to invest in biogas production. The presence of failed investments has created the notion that there is not high profitability in biogas production which contributes to the slow diffusion of the technology in the region (Energy Community).
- **No observed benefits**: At the same time the positive benefits of biogas have not been observed by communities and locals so that people can realize the contribution of the technology to the environment and the local economy (Energy Community). Companies find it difficult to overcome the bureaucratic challenges to show the benefits

such projects could have. For instance, project ideas such as the connection of biogas production with the energy use of a local prison were immediately rejected as the bureaucratic obstacles would not let the implementation of such a project be realized (Thessaly Biogas Company A).

- **Energy Prices**: Production is often influenced by market factors such as the electricity prices. As the energy prices fluctuate depending on the energy market there is an unstable price on electricity. This affects biogas CHP production with the plants often forced to pause their production in order not to produce electricity with a price of zero (Thessaly Biogas Plant C).
- **Absence of Big Players**: The market leaders in energy production such as the big oil refineries or oil importers have not yet been interested in biogas production. This shows the fact that they recognize the problems in the industry. With their involvement in biogas and their expertise in upscaling production, the market would be in a different state (Natural Gas Expert).
- **Small Number of Biogas Plants:** The small number of biogas plants has an effect on the actions to improve the system. As the innovation system and the biogas companies are regularly considered small, policymakers are not taking strong actions to solve problems or address the needs of the stakeholders (Thessaly Biogas Company A).

Other: Some of the identified problems exist as more than one type of failure or are depended on unsystematic events such as natural disasters:

- **Digestate By-Product Management**: The digestate management is a problem for many of the biogas companies as it has to be transported to end users such as farmers. At the same time farmers are reluctant to use it as they are unaware of its beneficial use in agriculture (Biogas Entrepreneur). As companies are forced to manage the disposal ot this by-product they bear all the logistic costs for the transportation (Thessaly Biogas Company B).
- **Effects of Daniel Storm**: As the storm of 2023 destroyed a large number of farming resources (Energy Community), they have also affected the biogas companies in terms of available resources and in terms of costs. The additional capital expenses and the operational costs the companies experienced, negatively affected the profitability of the companies (Thessaly Biogas Company A).

The most frequently mentioned problems

Aiming to provide an overview of the existing problems in the Greek Biogas Innovation System the main problem identified was related to the capacity of the electricity grid as 8 participants identified this issue. Problems such as the availability of biomass (6 out of 10) and waste management from the side of farmers (5 out of 10) also contribute to the existing condition of low biogas production. Additionally permitting challenges and the biomass market price have been identified by 4 participants. These problems come from different categories of failures and show that the difficulties the Greek Biogas Innovation System faces are not linked to one single source but rather a mixture of different issues.

5.2.2 Existing Regulations

During the interview process participants were able to expand on the main regulations that exist to support or control the biogas innovation system. The main regulations are related to environmental policies and market support actions. The results in a table format (Table 10) and in text are presented below.

Existing Regulations	Biogas Entrepreneur	Energy Community	Funding Organization	Thessaly Biogas Company A	Thessaly Biogas Company B	Thessaly Biogas Company C	Natural Gas Expert	Research Organization	Biomass Supplier	Flood Victim of Thessaly
Biogas Plants Environmental Regulations	Strict Environmental Regulations			X		X		X		
Market Support Actions	Additional FiT due to Energy Crisis			X	X	X				
Agricultural Wastes Management Regulations		X		X		X			X	

Table 10 Results: Greek Biogas Innovation System Existing Regulations

All Biogas Producers are obligated to follow **Environmental Regulations** such as the pasteurization of some of their feedstock (Biogas Entrepreneur), or reporting on their by-product management (Thessaly Biogas Company C). These regulations have been characterized as "too strict" as the lack of experience from the side of policymakers results in the creation of rules that do not support the diffusion of biogas technology and rather creates regulatory obstacles (Thessaly Biogas Company A) and complexity (Thessaly Biogas Company C).

Through the actions of the Biogas Association, it was possible for certain **Market Support Actions** to take place, and due to the energy crisis, an additional increase in the Feed-in-Tariff was approved (Biogas Entrepreneur, Thessaly Biogas Company A, Thessaly Biogas Company B). However, from the side of the participants, it was also mentioned that the existence of the FiTs and the market support are creating the circumstances for the demand for the technology to grow (Biogas Entrepreneur) but are not able to support the needs of the biogas industry it total (Thessaly Biogas Company C).

The **Agricultural Waste Management Regulations** were mentioned as the main way to force the waste producers such as farmers to organize their actions regarding the management of their activities' wastes. As the issues with the monitoring of farmer's waste management have been mentioned, these regulations often are seen as less strict than the ones for biogas producers (Thessaly Biogas Company A, Thessaly Biogas Company B). This refers mainly to the small-sized waste producers as the organizations with a large amount of wastes are monitored more intensely through the Waste Management Database and comply fully to the environmental regulations (Biomass Supplier). On the other side, for small-sized livestock farmers, the regulatory framework is seen as complex however there is existent interest in complying with the administrative requirements (Energy Community).

5.2.3 Needed System Changes

As the existing regulatory framework addresses a part of the observed problems, the needed system changes mentioned during the interview process cover a broader part of the system and aim at the specific issues related to biogas. The needed system changes below provide a comprehensive overview of the points that regulations and government actions need to support in order for the Greek Biogas Innovation System bottlenecks to be addressed. The results in a table format (Table 11) and in text are presented below.

Needed System Changes	Biogas Entrepreneur	Energy Community	Funding Organization	Thessaly Biogas Company A	Thessaly Biogas Company B	Thessaly Biogas Company C	Natural Gas Expert	Research Organization	Biomass Supplier	Flood Victim of Thessaly
Incentives for Biomass Production	Cover Crops, Energy Crops									
Upgrade Capacity of Electricity Grid	X	X		X	X	X		X		
Strong Farmer Regulations	X				X					
mplementation of Energy Community Regulatio	Production of Biomass by Energy Communities									
Needed Regulations for the Biomethane Market	X			X	X	X	Customer Pricing			
Support Technology Advancements	X							Utilization of Heat Production		
Assist Cooperation		X								
Financial Tools					X		X			
Biomass Centralization		X		X		X				
Paperwork		X		X	Faster Permiting		X			
Need to inform the public			X		X					X
Improvement of Road Infrastructure				X						
Centralized Biogas Public Body						X				
Data Base Creation						Knowledge Diffusion				
Education and Creation of Experts	X					MSc Programms , Training Tools				
Technical Requirements for Biogas Injection							X			
Transparent Regulatory Framework						X	X		X	

Table 11 Results: Greek Biogas Innovation System Needed System Changes

Focusing on the existing infrastructure problems, the need for an **Upgrade of the Capacity of the Electricity Grid** was the most frequent point mentioned. This change in the Greek Biogas Innovation system was mentioned by 6 participants as this practical issue needs to be tackled through government support (Thessaly Biogas Company A). As a response to the existing problems biogas companies face with their expansion, the upgrades in the capacity f the electricity grid would also help the green transformation in general (Natural Gas Expert), and provide higher quality connection for certain areas (Energy Community). Currently, there are existing ongoing projects related to the revolutionization of the existing electricity infrastructure however there are still many actions that have to be taken in many regions (Research Organization).

The need in infrastructure investments includes also the **Improvement of Road Infrastructure.** As the current state of many roads in rural areas such as Thessaly is poor, companies would benefit by a better road network that would connect them with more farmers and suppliers without the need to construct the roads themselves (Thessaly Biogas Company C).

The performance improvement of the Greek Biogas Innovation System also is related to the **Needed Regulations for the Biomethane Market**. As mentioned by 5 participants, the existing regulatory system does not include any market formation or technical specifications regarding biomethane production resulting in no production volumes. As the expectations for such a framework are high companies are currently unaware of the needs and requirements they have to follow, making it difficult to proceed in any discussions with natural gas companies (Thessaly Biogas Company A) or make investment plans (Thessaly Biogas Company C). For stakeholders to understand how they are going to integrate biomethane technology in the Greek Biogas Innovation System there are certain **Technical Requirements for Biogas Injection**, mixing, pricing regulations, and the specifications of the locations where the biomethane could be injected into the natural gas network (Natural Gas Expert). Additionally, there are certain measures such as mandatory mixing in the natural gas network (Biogas Entrepreneur) or additional FiTs that would provide biogas producers the incentives to make such investments in the biogas production units (Thessaly Biogas Company A, Natural Gas Expert).

As mentioned in the Observed Challenges, **Paperwork** entails many of the bureaucratic obstacles companies face to receive the necessary permits. A need for less complexity was mentioned by 4 participants, not only for a need to make the processes faster (Thessaly Biogas Company A, Thessaly Biogas Company B, Natural Gas Expert), but also to help simplify the requirements for many stakeholders such as farmers helping them in such a way so that they can better comply with the existing regulations (Energy Community).

This need expressed by the participants is also related to the actions required for a **Transparent Regulatory Framework.** As the needs of the stakeholders need to be represented a transparent and clear framework related to biogas production could provide a holistic approach to take into account the issues of the industry, the goals set, and the rules of the game (Natural Gas Expert). Certain issues such as the confusion of biogas producers regarding the rules they should follow (Thessaly Biogas Company C) or the confusion of what is considered a waste for biogas production (Biomass Supplier) would be avoided if the regulatory framework was clear enough.

In addition to these needs for less complexity and transparent regulation, participants have also expressed the need for **Strong Farmer Regulations**. As has been mentioned that the waste management rules for farmers are not entirely practiced, there is a need for farmers to comply with the existing regulations so that the total volumes of waste are processed for biogas production and their environmental impact is minimized (Biogas Entrepreneur). Additionally, there are no strong incentives for farmers the use the biogas production by-products (digestate), and for this material to be effectively managed these stakeholders should be encouraged to utilize its use (Thessaly Biogas Company B).

The issue of farmer regulations could be more efficiently managed through the monitoring of biomass and waste activities through the **Database Creation**. The existing volumes of waste are currently monitored through the National Database of Wastes however as mentioned not all the produced quantities are registered in this system. Through the creation of a database containing all the existing information on the industry, production numbers, feedstock details, and relevant biogas system information could enhance not only the knowledge diffusion but also create transparency in the system and legitimacy among the stakeholders (Thessaly Biogas Company C).

This is highly linked with the recommendations for the creation of a new public administration body, a **Central Biogas Public Body**, that can support biogas activities with the ability to solve problems and support the stakeholders without creating conflicts of interest (Thessaly Biogas Company C).

An existing challenge around the availability of the needed resources for biogas production could be resolved through actions toward **Biomass Centralization** systems and it has been mentioned by 3 participants during the interviews. Either through systems for an organized organic waste gathering in communities and cities (Energy Community), or in the agriculture waste sector through an organized collection of biomass (Thessaly Biogas Company A, Thessaly Biogas Company C), these actions can drive logistics costs down and also provide stability of supply for companies to ensure production goals.

Incentives for Biomass Production would also provide the basis to revolutionize the agricultural sector that has been recently devastated by environmental disasters. Cover crops and energy crops can be supported through the rotational farming conditions and create a surplus in the availablility of residues for energy production (Biogas Entrepreneur).

Other needed changes in the system are related to **Implementation of Energy Community Regulations** by encouraging participation with incentives for biogas production by energy communities (Biogas Entrepreneur), actions to **Assist Cooperation** between stakeholders and actions to **Inform the Public** and create a positive image around biogas technology (Funding Organization, Thessaly Biogas Company C).

Finally, there are more needs such as the **Education and Creation of Experts** through the creation of MSc programs and training tools on biogas technology (Thessaly Biogas Company C), additional **financial tools** that will provide funding fast (Thessaly Biogas Company B, Natural Gas Expert) and **Support on Technology Advancements** capable to revolutionize the industry through the addition of new biogas innovations (Biogas Entrepreneur), and the utilization of existing technologies missing from the current system such as methods to utilize the CHP produced heat for community benefit (Research Organization).

Overall the majority of participants focused on the needs to change current problems in the electricity grid capacity, the availability of wastes for biogas production, and the missing regulation framework that should focus on biomethane production. Although these interventions are required to support the biogas innovation system it is important to also understand the other mentioned changes with less frequent appearance as they focus on existing issues of the Greek Biogas Innovation System.

5.3 Inclusion of Communities

One of the aims of the interview process was to also collect the views of stakeholders in the Greek Biogas Innovation System on the inclusion of communities. Moreover, indirectly related stakeholders such as people from the area were able to also share their thoughts on biogas and the needs people such as flood victims face.

5.3.1 Perspectives for inclusion of communities

To understand the views of participants on the importance of community engagement the analysis identified initially the perspectives regarding the inclusion of communities in the biogas innovation system. The results in a table format (Table 12) and in text are presented below.

Perspectives for inclusion of Communities	Biogas Entrepreneur	Energy Community	Funding Organization	Thessaly Biogas Company A	Thessaly Biogas Company B	Thessaly Biogas Company C	Natural Gas Expert	Research Organization	Biomass Supplier	Flood Victim of Thessaly
Improvement of Biogas Image	Community empowerment and benefits enhance biogas image			X					X	
Use of Community Wastes	X	X		X			X			
Importance of Citizen Information			X							
Creation of Economies of Agglomeration						X				
Energy as a Public Good							X			
Community Benefit								X		X
Environmental Benefit										X

Table 12 Results: Stakeholder Perspectives for the inclusion of communities

The inclusion of communities and locals in the biogas innovation system has a positive influence on the biogas image and the success of the innovation system is based on the creation of a positive environment around it (Biogas Entrepreneur, Biomass Supplier). Actions that encourage the engagement of communities can provide ways to utilize resources such as community wastes (Thessaly Biogas Company A) while inclusion has also been understood as a way to effectively inform and educate the locals on the benefits of biogas technology (Funding Organization). Through the engagement of communities in the biogas innovation system it is possible to benefit local communities and the environment as well (Flood Victim of Thessaly) while it is also possible to create economies of agglomeration that in total support the technology through the creation of experts and biogas expertise (Thessaly Biogas Company C). Finally as energy should be a public good, as communities and local residents should be encouraged to take action and benefit from the energy produced in their region (Natural Gas Expert).

5.3.2 Needs & Issues of Thessaly Communities

The communities and people in the region of Thessaly have certain needs that need to be addressed. The results in a table format (Table 13) and in text are presented below.

Needs & Issues of Thessaly Communities	Biogas Entrepreneur	Energy Community	Funding Organization	Thessaly Biogas Company A	Thessaly Biogas Company B	Thessaly Biogas Company C	Natural Gas Expert	Research Organization	Biomass Supplier	Flood Victim of Thessaly
Flood Damages	X	Reduction of Animal Numbers		X						X
Issue of Biogas Smell				X	X					X
Need to Observe the Benefits				X	X					X
Energy Cost Reduction	Biogas cannot reduce energy									X
Health & Safety										X
Financial Aid										X
Environmental Benefit										X
Anger Towards the Government										X

Table 13 Results: Existing Needs & Issues of Thessaly Communities

One of the biggest issues local communities face are related to Flood Damages due to the catastrophic storm Danies in September 2023 with actions required to support flood victims (Biogas Entrepreneur). The storm of 2023 has destroyed large numbers of farming lands, and killed thousands of animals (Energy Community), while people from local communities have experienced the destruction of their houses, and whole communities in total have seen the effects of the storm (Thessaly Flood Victim). There is a sufficient need for financial aid to the region however it is not considered enough to support the costs of infrastructure destruction while there is anger towards the government for the limited support and the situation people are at the moment (Thessaly Flood Victim). The high energy costs due to external reasons have also contributed to the problematic situation and there is a need for alternative methods to provide cheap energy for the locals (Biogas Entrepreneur, Thessaly Flood Victim).

Additionally, communities in Thessaly have not yet observed the benefits of biogas production (Thessaly Flood Victim) and there are existing issues with complaints about the biogas plants smell (Thessaly Biogas Company A, Thessaly Biogas Company B, Thessaly Flood Victim). There are concerns also regarding health & safety issues related to biogas in the area while it at the same time people have also the need to know if such technologies have environmental benefits (Thessaly Flood Victim).

5.3.3 Challenges to Encourage Involvement

For people to actively participate in the biogas innovation system there are certain challenges that may hinder the success of such initiatives. The results in a table format (Table 14) and in text are presented below.

Challenges to encarouge involvement	Biogas Entrepreneur	Energy Community	Funding Organization	Thessaly Biogas Company A	Thessaly Biogas Company B	Thessaly Biogas Company C	Natural Gas Expert	Research Organization	Biomass Supplier	Flood Victim of Thessaly
Limited Knowledge	Limited knowledge on Biogas	X	X	X	X	X				X
Not organized community waste collection system	No organized collection									
Missconceptions		NIMBY,Negative Biogas Perception	Fear	X	X	X				
Misscomunication			X				X			
Municipality Role							Slow at Taking Action			
Farmer Problems	X				X					

Table 14 Results: Challenges to Encourage Community Involvement

Communities in Thessaly have very limited knowledge of biogas technology as mentioned by 7 participants as the environmental benefits and social benefits are not well spread in the communities (Thessaly Biogas Company B, Thessaly Flood Victim). In addition, misconceptions related to biogas exist with many communities forming negative perspectives towards the technology (Energy Community). Farmers who are members of the Thessaly communities are also skeptical about using the by-products of biogas production as fertilizers due to their limited knowledge of the technology (Thessaly Biogas Company B).

For organizing community action and encouraging participation miscommunication also plays a negative role in affecting the difficulty in cooperation. Finally, the role o Municipalities also creates problems as they are slow at taking action and helping people observe the benefits of a technology (Natural Gas Expert) while there are also no plans for organized communite waste collection systems that could help people contribute to biogas production through their wastes (Biogas Entrepreneur).

5.3.4 Existing Tools, Actions & Policies

The results in a table format (Table 15) and in text are presented below.

Existing Tools, Actions & Policies	Biogas Entrepreneur	Energy Community	Funding Organization	Thessaly Biogas Company A	Thessaly Biogas Company B	Thessaly Biogas Company C	Natural Gas Expert	Research Organization	Biomass Supplier	Flood Victim of Thessaly
Flood Support Mechanisms	X									X
Social Benefits	X				X	X		X		
Informative Actions		Workshops, Festivals	X	X	X					
Energy Community Actions		Combat Energy Poverty			X		X	X		
Support Local Communities				Employ Local	X	X				
CrowdFunding: Genervest by GreenPeace							X			
Coupon Cards										X

Table 15 Results: Existing Tools, Actions & Policies for Community Inclusion

At the moment there are certain tools for communities to be supported such as the Flood Support Mechanisms that provided some financial resources during the period of the storm. People received coupon cards for local businesses however such actions did not have a positive impact on locals' support from the government (Thessaly Flood Victim).

On the support of biogas community engagement and acceptance, Energy Communities have active roles in Thessaly aiming to "combat energy poverty" with their investment co-creation actions (Energy Community, Thessaly Biogas Company B, Research Organization). In addition informative actions such as workshops, info sessions, festivals (Energy Community), or field trips to plants (Thessaly Biogas Company A) are organized to support the education of communities on the technology and its diverse benefits.

Through the legislative framework, a certain percentage (around 3%) of the biogas plant revenues goes to municipalities for community support (Biogas Entrepreneur, Thessaly Biogas Company B) while all companies aim to employ people from the local communities and support local industries in their operations (Thessaly Biogas Company A, Thessaly Biogas Company B, Thessaly Biogas Company C).

An additional tool mentioned for the support of local projects are also existing CrowdFunding tools such as th Genervest platform by GreecePeace that gives people the opportunity to invest in renewable energy projects and receive economic returns (Natural Gas Expert).

5.3.5 Recommendations for Community Benefit

Finally, the interview process identified recommendations that could strengthen the community participation in the Greek Biogas Innovation System through different tools and regulations. The results in a table format (Table 16) and in text are presented below.

Recommendations for Community Benefit	Biogas Entrepreneur	Energy Community	Funding Organization	Thessaly Biogas Company A	Thessaly Biogas Company B	Thessaly Biogas Company C	Natural Gas Expert	Research Organization	Biomass Supplier	Flood Victim of Thessaly
Low energy costs to citizens	Benefit Community through cheap electricity and gas									X
Energy Community Engangement	Alliences	X								X
Public Investments	X									
Virtual Net Metering		Applied already in PV			X			X		X
Biogas from Community Wastes					X					
Encourage Involvement through Incentives					Coupon Cards					X
Action Groups										X
Design Based on Community Needs										X
Autonomous Schemes										X
Farming Cooperatives Involvement								X		

Table 16 Results: Recommendations for Community Benefit

The application of Virtual Net Metering which is currently applied in PV has potential benefits for communities (Energy Community, Thessaly Bioags Company B, Research Organization, Thessaly Flood Victim). The utilization of community wastes from biogas companies (Thessaly Biogas Company B) the creation of action groups to support information actions, the development of autonomous schemes, and the design of the system based on the needs and problems of locals could benefit not only the communities but the system itself (Thessaly Flood Victim).

There is a certain need for further Energy Community engagement through the creation of alliances and the enforcement of Farming Cooperatives while there is a requirement to find ways to secure low energy costs for citizens and especially citizens who have experienced the effects of the Daniel storm (Energy Community, Thessaly Flood Victim). Such actions should be encouraged through incentives for the local communities (Thessaly Biogas Company B, Thessaly Flood Victim).

6 Discussion

In the discussion part, the main findings are synthesized to form the main answers to the research question set in this study. The results are also supported by existing literature to validate certain findings. In this part recommendations for policy and practice are also proposed while the contributions of this research are also highlighted. Finally, the limitations of this study and the relevance of this Master's thesis to the MOT MSc programme are presented.

6.1 Interpretation of Key Findings

The key findings of this research are directly related to the main question regarding the systemic barriers preventing the growth of the Greek Biogas Innovation System. In order to establish this point, an initial analysis and mapping of the Greek Biogas Innovation System through a case study in the Thessaly region has taken place. Interpreting the research findings, this study will initially describe the Greek Biogas Innovation System following an evaluation of the systemic barriers identified and barriers to stakeholder participation. The main findings are additionally related to the literature review to further validate the results of this research.

6.1.1 The Characteristics of the Greek Biogas Innovation System

The Greek Biogas Innovation System exhibits a well-developed and complex network of stakeholders related to biogas production, innovation, financing, and technology expansion. This network includes biogas companies, and biomass suppliers, such as agricultural and livestock farms or food processing industries. Municipal authorities and government bodies have multiple roles in monitoring the permitting process for new plants and the provision of incentives for biogas production. Research institutes mainly contribute to knowledge development, pilot projects with biogas companies, and information provision in cooperation with government bodies. Main research is supported through EU funds and Research Funding Organizations existing in the country. Financial organizations such as regional and national banks as well as European funds are mainly the first entities supporting the financing of new commercial projects.

From the system functions viewpoint, entrepreneurial activities are mainly based on the existing applied technology on biogas with no projects related to biomethane or new innovative projects. Knowledge development actions are mainly supported by universities on research related to biogas and biomethane technology, or digestate management. Knowledge diffusion is realized through workshops, conferences, and events between the Hellenic Association of Biogas, Companies, and universities complimented by European programs and informal knowledge sharing between companies. Market Formation Actions are mainly driven by the Feed-in-Tariffs that are based on fixed prices for produced electricity with no additional tax incentives of direct government funding for commercial projects. Mobilization of Resources is characterized by scarcity of experts and educational tools while financial resources are mainly available through bank loans for commercial plants or Government and EU resources for research purposes. The feedstock resources are considered available however bear high logistics costs. Infrastructure has limitations based on the capacity of the electricity grid however a possible transition to biomethane production could be supported by the already established infrastructure on Natural Gas and the abundance of experts in that field. Legitimacy Formation is supported by common interests with other RES in terms of electricity production upgrades however technologies such as PV and wind turbines act competitively for construction permits based on the existing limited capacity of the grid. The biogas association of Greece, the Hellenic Biogas Association is the main body advocating the interests of the biogas producers and driving knowledge diffusion and networking actions. Table 17 below presents the TIS functions in the Greek Biogas Innovation System including certain indicators and characteristics of the system.

Functions	Indicators
Commercial Projects and Initiatives	Commercial Plants in Close Proximity Few Innovative Projects No biomethane Plants
Knowledge Development Actions	NTUA and UTH research Many low TRL projects
Knowledge Diffusion	Workshops Conferences Events EU platforms: Project "ALPHA"
Guidance of the Search	Existing Regulations on Biogas: Environmental Regulations No Institutional Framework on Biomethane
Market Formation Actions	Feed-in –Tariffs No Tax Reductions No Government Funding for Commercial Projects
Mobilization of Resources	No Experts, Government Research Funding LEADER programs Available feedstock, No organized collection Limited Electricity grid Capacity
Legitimacy Formation	Hellenic Biogas Association, Shared Interests with other RES

Table 17 Greek Biogas Innovation System functions

Stakeholder relations are characterized by cooperative and competitive elements between different actors. Biogas companies have both competitive and cooperative relations with biomass suppliers for the utilization of feedstock while they participate in joint actions with academia or the Hellenic Biogas Association for common projects. At the same time there are connections between energy communities and locals with academia, EU, and farmers for the initiation of community-produced biogas while the expected regulations and framework of biomethane will initiate a new course of relations and collaborations between academia, companies government bodies, natural gas suppliers and biomass suppliers.

6.1.1.1 Empirical Results and links to Existing Literature

The TIS presented above, exhibits multiple relations and actions that currently drive biogas production and innovation and it is possible to identify common characteristics in other studies related to biogas either from past Greek studies or other country examples.

It would be initially important to note that through this study all the TIS functions were able to be identified and expanded under the Greek Biogas TIS. As a result, biogas in Greece exhibits the characteristics of a Technological Innovation System related to previous TIS literature (Bergek et al., 2008; Hekkert & Negro, 2009) and additionally includes indicators related to Biogas TIS (Nevzorova, 2022).

Certain characteristics of the Greek Biogas Innovation System can also be observed in other international studies. The Brazilian Biogas Innovation System has several common features such as government bodies, biogas companies, third parties, research institutions, biomass suppliers, and financial organizations involved in the system (De Oliveira & Negro, 2019) with the Greek Biogas Innovation System. In addition Borges et al., (2023) also mentions the lack of tax incentives, the presence of events and conferences, and the presence of financing lines for biogas projects as common characteristics between the Brazilian Biogas Innovation System and the Greek Biogas Innovation System.

The Russian Biogas TIS also presents common characteristics with different sectors such as agriculture, energy, and industry sector involvement while competition between other energy sectors also exists in both Greece and Russia (Nevzorova, 2022). Certain points related to the Greek Biogas Innovation System can also be seen in European countries such as the presence of Feed-in -Tariffs in Germany and Italy (Nevzorova & Karakaya, 2020; Torrijos, 2016) and common drivers such as the need for energy security (Wilkinson, 2011) mentioned also in the interview findings (Energy Community).

The identification of the key actors in the Greek Biogas Innovation System presents additionally common points also with the Swiss Biogas TIS with the involvement of biogas plants, farmers, food industries, banks, and the biogas association of the country (Markard et al., 2009). The presence of certain stakeholders has also been mentioned in previous studies related to the Greek environment. Regarding identified stakeholders, Panoutsou, (2008), mentions the existence of environmental NGO's, biomass suppliers, and governmental bodies related to the system.

These similarities between the Greek Biogas Innovation System and other countries' Biogas TIS indicate the common points existing. Additionally, these similar characteristics help understand that the Greek Biogas Innovation System can be analyzed under the TIS notion as multiple elements of the biogas presence in Greece refer to the TIS analysis of other successful or growing Biogas TIS.

6.1.1.2 Schematic Representation of the Greek Biogas Innovation System

Overall, as can be seen in the figure below the main identified stakeholders are categorized on international, national, and regional levels. As this case study was conducted in the region of Thessaly, the area represents a characteristic Greek region, and the stakeholders involved directly and indirectly.

The figure below presents the proposed framework for the analysis of the Greek Biogas Innovation System by the author of this thesis. Inspired by the work of Nevzorova, (2022) the main supply chain is set linearly in different geographical contexts. Under this proposed framework it is possible to organize the activities and the direct and indirect stakeholders in the system as well as understand the current relations between stakeholders.

Arrows in black represent strong relations between stakeholders while the weak relations are illustrated by arrows in light green. Compatitive relations are in yellow dot lines, negative relations are in red lines and relations of advocacy and administrative issues are displayed in orange. As can be seen in the figure biogas companies have strong relations with stakeholders such as biomass suppliers, the biogas association, biomass transporters, and construction companies while they present negative relations with municipalities and communities based on this study's findings. The Hellenic Biogas Association is also interesting to analyze as it presents advocacy relations with government bodies, strong relations with research institutes, and weak relations with energy communities.

Stakeholders are placed between three different geographical contexts depending on their actions. As a result, the EU is placed at an international level while construction companies are placed at all levels as they operate internationally, nationally, and regionally. Biogas production is dependent on regional factors and the Hellenic Biogas Association has national standing. Similarly, the illustration can be understood based on this description for the rest of the stakeholders depicting the characteristics of the system.

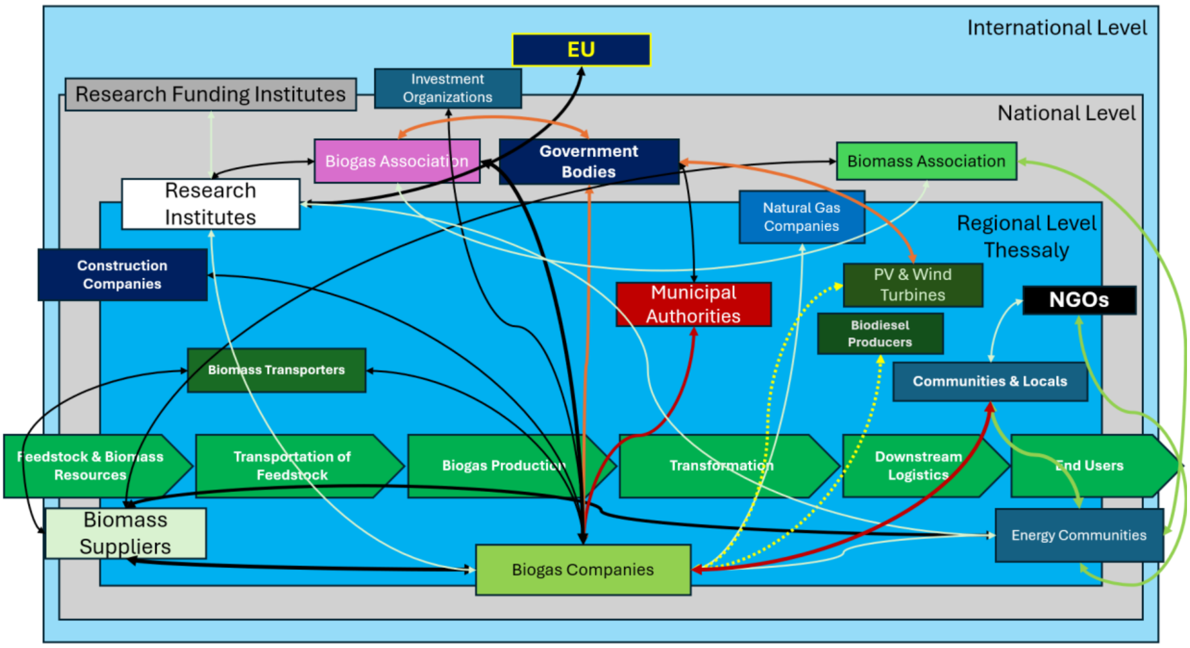

Figure 4 Stakeholders involved in the Greek Biogas Innovation System. Own Image inspired by (Nevzorova, 2022)

6.1.2 Empirical Findings on the Existing Systemic Barriers of the Greek Biogas Innovation System

In this part, the empirical findings on the existing barriers of the Greek Biogas Innovation System are presented relating to both the national system and the regional system around the biogas technology. The Greek Biogas Innovation System, particularly the existing system examined in the case study on the Thessaly region, the most productive region in terms of agricultural resources and biogas production, presented certain systemic barriers that can be classified under the systems failure framework with the addition of external, interrelated problems and market issues.

Infrastructure problems are mainly related to the outdated electricity grid, an issue that leads to the limited capacity of the grid to handle the electricity production from CHP Biogas plants and also other RES. This limitation delays the issuance of new construction permits for biogas plants thus slowing down the opportunity for new plants to be established in feedstock-rich areas. Low-quality road infrastructure in many areas brings operational challenges for biogas plants requiring the companies to construct their access roads, while low scientific output restricts the application of innovative solutions that could benefit production.

Institutional problems are related to the permitting process, regulatory gaps, and slow funding process, creating a complex bureaucratic environment with large waiting times and bottlenecks in the administrative issues around biogas production and the construction of new plants. While regulations exist to force biomass producers such as livestock farmers, agricultural farmers, and food processing industries to follow waste management plans and provide their wastes as feedstock to biogas plants, they are weakly enforced in all regions and cases, creating as a result a problem with the supply of feedstock for biogas companies.

Problems are located also between the interactions of stakeholders. Strong network failures between members of the Hellenic Biogas Association occur due to the closed relations between the existing members, making it difficult for new entrants to exchange information and enter the industry. Even between the existing producers, information exchange is a problematic issue with plants in close proximity having antagonistic relations due to feedstock supply competition. Additionally, past failures of cooperative projects have led to a negative image related to collaborative initiatives. Regarding the relations between biogas technology and the public, the media have not supported the expansion of the technology portraying mainly negative events related to biogas projects while also having an effect on local opposition. Local communities are hostile to the implementation of biogas plants in the Thessaly region due to various factors such as the biogas plants' odors, their lack of information about the technology, and the limited observed benefits.

Capability challenges include the unreliable availability of biomass feedstock due to the lack of the organizational capabilities to arrange systems of collection of resources leading to high logistics costs and unstable biogas qualities. There is an evident lack of clear information on available resources, practices, and quality standards, and a lack of experts specialized in biogas production.

Through the findings, it was possible to recognize also other systemic barriers that correlate more to the existing market and other issues identified above. The problems in the availability of resources despite their evident abundance, have led to certain feedstocks forming prices that eventually increase the biogas production costs. At the same time, the fluctuating energy prices have led the electricity production from biogas to be economically inefficient highlighting the dependence of biogas from this energy transformation through the CHP technology.

In addition to that the lack of successful cases has created the perception of low profitability on biogas projects, preventing potential investors. This is also coupled with the current lack of interest from the side of big energy production companies of Greece forming, as a result, a hesitation to future investors to enter the biogas production as there are no strong indications that such projects can be profitable. Lastly, the hostility from communities affecting the acceptance of new and existing problems is further affected by the limited or no observed benefits from biogas production.

Besides these issues, the Daniel storm created additional operational costs and capital expenses for producers and a large loss of agricultural and livestock capital for the agriculture sector generating a sock in the system. This problem as an external factor is positioned outside the system failure framework related to the Greek Biogas Innovation System and is considered an additional issue related to the infrastructural capabilities of the region and the flood defence mechanisms. At the same time as an issue, it has a direct and indirect impact on the productivity of the region magnifying the existing analyzed problems.

The inclusion of local communities in the innovation system can be understood as an additional systemic barrier preventing the further adoption of biogas technology. Mainly through their hostility, locals have negative perspectives towards the implementation of biogas projects. As has been mentioned above certain issues prevent the locals from forming a positive attitude toward biogas. On the other hand, directly involved stakeholders understand that the participation of communities and their active involvement could have a beneficial effect on the system. These benefits would be observed by improving the image of biogas technology following a more positive attitude towards it, utilizing community wastes leading to added feedstock and more available resources, and by providing economic support to these communities through lower energy prices and agglomeration benefits through the close proximity of new plants and the creation of regional expertise.

However, there are certain problems in encouraging involvement in the first place as the limited knowledge of biogas, the existence of misconceptions and the hesitation by local community farmers to use the by-products of biogas production as well as the lack of communication channels to organize the community involvement are certain challenges to encourage involvement. These challenges contribute to the existing situation of biogas-hostile communities and as certain permits and operations depend on municipal councils and local acceptance, the growth of the biogas sector is dependent on the attitudes of each region towards the technology.

6.1.2.1 Barriers Discussed in Biogas Literature

6.1.2.1.1 Systemic Barriers in Literature

The systemic barriers identified through the case study in the region of Thessaly can be supported also by existing international literature and Greek studies. The problematic infrastructural obstacles such as the insufficient grid infrastructure related to the Greek Biogas Innovation System are also systemic barriers to renewable energy technologies in southern countries of Europe (Lehmann et al., 2012) including Greece (Gajdzik et al., 2023) or non-EU countries like Chile (Nasirov et al., 2015).

In addition, Foxon et al., (2004) discusses system failures in renewable energy technologies related to policy gaps, the need for larger players that could support the financing of larger projects, and the need for experts with diverse skills across all the stages of the development and implementation of renewable technologies. The issues of renewable energy resources allocation and organization to support the RES production and the lack of educational and expertise programs are also considered barriers in other EU countries such as Poland (Gajdzik et al., 2023). These issues are able to support existing problems in the Greek Biogas Innovation System which as a renewable energy system faces similar problems.

Moreover, problems across the European Union can be related to identified barriers in this study such as the lack of knowledge required to implement RES projects from the side of communities (Streimikiene et al., 2021) and lack of scientific infrastructure to support innovative pilot projects (Lehmann et al., 2012).

From a global perspective including various developed and developing countries on biogas technology, Nevzorova & Kutcherov, (2019) identified systemic barriers similar to this study's findings. As a result, insufficient R&D funding, and the unclear environment around the biomethane and biogas injection are some of the identified issues. At the same time, issues of the Greek Biogas Innovation System such as the low public participation in the biogas plants odor problems and the low degree of public knowledge on biogas, constitute problems that are found across the world, concerning the biogas technology.

In Greece, problems identified in the literature presented can be validated also through this study's findings. The existing problems of collaboration and the lack of awareness among farmers have remained through the years (Panoutsou, 2008; Sioulas Konstantinos, 2008). Regarding community participation in the system, issues such as bureaucratic complexity, negative perceptions towards biogas by-products and the low level of community biogas knowledge are existing issues in both this study and past studies (ISABEL, 2017b).

6.1.2.1.2 The barrier of Natural Disasters

The flood issues of many regions in Greece including Thessaly have not been only a recent problem, with certain natural events occurring in 80s and 90s, many years before the discussed events of the Daniel storm. The current measures for the prevention of floods, already present in the region, and the discussions through the years regarding proposed changes to strengthen the existing infrastructure (Koutsoyiannis & Mimikou, 1996) highlight the aspect of infrastructural and institutional failures in the flood management field.

Consequently, these failures are not directly related to the systemic failures of the Greek Biogas Innovation System and through this study's empirical findings, constitute external barriers to the Biogas sector that hinder the technology's adoption and diffusion. As a result, these external effects, failures of other systems and more related to complex infrastructure systems management (Yonat et al., 2023) and the management of such mechanisms in the case of extensive rainfall, fall outside the scope of this study.

However, it is important to mention the impact of natural disasters as a parameter in this study. Previous research also underscores this characteristic with Ahmed et al., (2023) highlighting the negative effect of natural disasters on renewable energy innovation systems leading to several disruptions in the innovation supply chains, destruction of resources, investment delays, and infrastructural destructions that affect the performance and development of renewable technologies. In addition, Zhao et al., (2022) also underscores the effect of natural disaster shocks in energy innovation with such effects being observable through the decrease of R&D investments, and new patents while the authors also highlighted the strong and lasting effect these disasters have on the technology development. These findings thus, relate to this thesis's findings regarding the effect of Daniel Storm as a natural disaster in the development of biogas technology and highlight the importance of external interruptions to the technology adoption. Through this point, it is possible to relate the effect of climatic events to the system failures of a Technological Innovation System, as systemic imperfections linked to Government actions and measures to prevent catastrophes of external sources lead to complications in other systems such as the biogas innovation system examined in this study.

6.1.2.2 Schematic Representation of the Systemic Barriers

The identified systemic barriers, supported through existing literature would be more clear to be understood under the context of the figure presented in Figure 5. As a result, delineating the different sectors involved and placing the empirical systemic barriers close to the different sectors can help organize the different problems. This illustration contains this study's empirical data and it is inspired by Nevzorova, (2022).

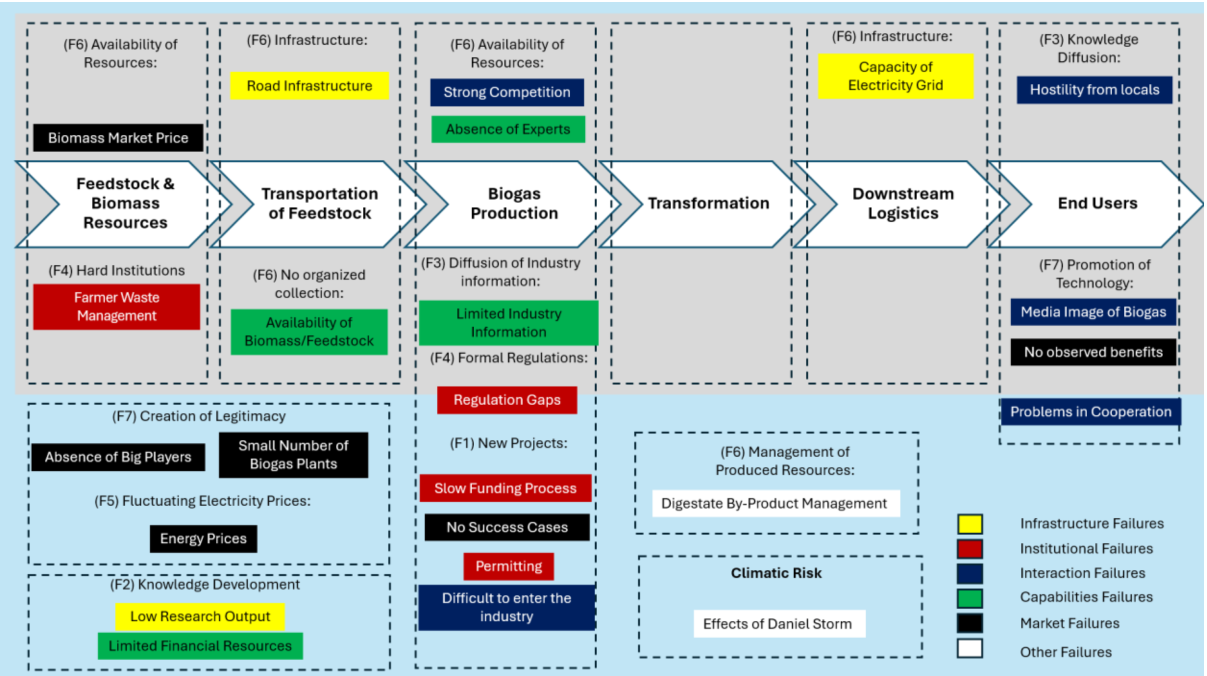

Figure 5 The main systemic barriers affecting the Greek Biogas Innovation System. Own image inspired by (Nevzorova, 2022)

Based on the figure above certain barriers are related to the feedstock and biomass resources, their transportation and availability such as the institutional issues of the farmer waste management regulations, and market issues such as the market price of biomass. Additionally the availability of biomass as a capability failure is linked to the lack of organizational capabilities from the side of both suppliers and producers to organize the collection and stable supply of biogas resources.

Biogas production failures are related to resource mobilization due to the existing competition for available resources and the absence of experts while knowledge diffusion functions link to capability failures as a result of the limited industry information available. Additionally, the TIS function related to formal regulations presents institutional failures such as observed regulation gaps while new projects are hindered under institutional failures (slow funding process and permitting), market failures (no success cases), and interaction failures as it is difficult to enter the industry.

On the downstream logistics side, the main infrastructure failure of the existing grid capacity is limiting the industry's expansion. End users such as local communities showcase the existence of knowledge diffusion problems as information about biogas is not available to locals creating interaction failures with hostile relations between communities and producers. Additionally, the creation of legitimacy is hampered by market failures (no observed benefits) and interaction failures as the media do not promote the technology.

Other systemic barriers observed related to the current creation of legitimacy (small number of plants, absence of big players), knowledge development (limited financial resources and low research output) resource management (by-product management), and market formation (fluctuating energy prices) can also be regarded as systemic problems that affect the growth of the system.

Finally, this schematic representation also includes a box related to Climatic Risk. As discussed in the previous part, the external parameter of climatic risk leading to natural disasters does not directly link to the systemic barriers in a similar way that other system failures directly create problems in the biogas value chain. The effect of climatic risk, caused by systemic failures in effectively managing natural disasters and extreme climatic phenomena tends to create numerous problems across the entire value chain affecting suppliers, producers, and end users leading to substantial disruptions in the systems processes. As the effect of such disasters has such complex interactions with other existing systemic barriers it would be important for future research to cover this aspect in more depth.

6.1.3 Contribution to the research problem

The systemic barriers identified contribute to the existing research problem related to the national and regional adoption of biogas in Greece by providing a contemporary analysis of the existing environment. While certain barriers have been verified by Greek literature, the Greek Biogas Innovation System presents issues that currently exist also in other biogas TIS and other international RES systems in Europe.

As the situations in the country have changed, additional problems have emerged with this study being able to focus on such barriers. As a result through the initial identification of the system functions, different institutional, interactions, capabilities, and infrastructure failures were able to be identified while additional issues related to the market conditions and the effect of unexpected events such as natural disasters highlighted the broad spectrum of needed changes the system requires in order to foster biogas technology adoption.

Currently, the Greek Biogas Innovation System faces different challenges related to complex bureaucratic implications, infrastructure insufficiencies, problems in the acceptance of the technology, no organized allocation of resources, and numerous other imperfect conditions that prevent it from moving forward with the EU goals for energy transition.

In the next part recommendations derived from this study's findings based on the diagnostic capabilities of the system failure framework and the stakeholder participation approach are presented in order to demonstrate the needed changes the existing system necessitates.

6.2 Recommendations for Policy and Practice

After the detailed discussion of the system barriers in the Greek Biogas Innovation System, this study aims to provide recommendations aligned with the problem of biogas adoption. These changes mainly correspond to this study's empirical findings regarding the required system changes and recommendations for community engagement with biogas technology as well as to the empirical findings related to the system barriers identified in this study. All of the recommendations below directly relate to certain stakeholders that need to take action and address them.

6.2.1 Recommendations to Support Production

Upgrading the capacity of the electricity grid is an essential part of strengthening the existing system related to the transformation of biogas into electricity. Government investments in the expansion and modernization of the grid infrastructure will accelerate biogas production and lead the way for more available permits for new biogas projects. As a recommendation, this act will not only support the biogas technology but also foster the green energy transition for other RES.

For a more stable supply of feedstock in response to the problems with the availability of resources certain actions to centralize biomass gathering could be implemented. Third parties that enter between the supply and demand acting as centralized points for biomass could lower logistics costs scaling up the collection and delivery of feedstock. This would result in less complexity for both the supply and demand side while it would enable production and new entrants to enter the system. This solution can also be implemented by the cooperation between the municipalities and biomass suppliers in a joint action that would involve these stakeholders.

This study additionally highlighted the importance of actions to be taken in order to assist cooperation between all involved parties of the system. The weak relations between the identified stakeholders need to be strengthened by the Hellenic Biogas Association and Academia for joint actions in R&D and commercial projects to support the technology.

The development of educational and training programs is also recommended to be implemented by universities and Biogas Companies as it can create a skilled workforce capable of advancing the biogas sector. As a result establishing MSc programs, training tools and seminars on biogas technology will provide the necessary expertise to drive innovation within the organizations and support the long-term advancement of the biogas sector. In addition to that the role of academia should be strengthened in the system with research on applied solutions that will power innovation in the biogas technology leading to efficient production and increased innovation output.

6.2.2 Recommendations to address Institutional barriers

Moving to institutional recommendations there are certain important actions for Government Bodies to implement that will help address the existing bottlenecks in the system. The most important act that will revolutionize the existing system is related to the Regulatory Framework for Biomethane production. This framework has not yet been implemented by the Greek Government and needs to define clearly how the market will be formed, the technical specifications, injection standards, and the financial incentives for biomethane production. Providing clear regulations for biomethane production will encourage the development of the biomethane sector and enable biogas producers and new entrants in the industry to integrate biomethane production into the natural gas network.

Apart from biomethane production, there are existing needs for actions that will simplify bureaucratic processes, eliminate regulation gaps, and significantly benefit biogas production. The permitting process and the existing regulatory framework need to be streamlined and reorganized to address the related stakeholder needs. As problems with current environmental regulations for biogas producers and biomass suppliers lead to either bottlenecks or non-enforcement, incentives for the stakeholders that comply with the regulations will address this issue and promote especially farmers to follow the regulatory instructions for handling their wastes. This will lead to an increased availability of feedstock supply as quantities that previously were disposed of in the environment will be supplied directly for biogas production. Addressing this issue can also lead to lower prices for biomass as the increase in feedstock supply will lower the competition for the currently limited available resources.

All of the above regulatory actions would be easier to monitor under the creation of a central organizational body entirely centered on the Greek Biogas Innovation System. With all of the important permitting, regulatory, and system monitoring operations passing by a central system with available data on production, feedstock, and information of the biogas system at a national and regional level certain actions will be able to take place:

- Centralization of administrative procedures: Under a central public body that gathers all the administrative procedures, all stakeholders potentially involved with biogas will be able to follow clear processes on administrative matters. At the same time, the needs and requirements of the involved stakeholders will be gathered under one body that will be able to address them and integrate the needed changes in the administrative processes.
- Resource Management: Information gathered in a central database can help provide more efficient resource management and system monitoring. This will enable regulators and policymakers proceed to immediate actions for the system support while it will also provide indications on the regulation enforcement.
- Information Diffusion: Additionally a central public body will help knowledge diffusion aiding new entrants gather the needed information on biogas production and available resources.

6.2.3 Recommendations for community engagement

In order to help biogas adoption and acceptance at a regional level, communities will play a crucial role and their involvement should be supported. This can be done either by their active involvement in biogas projects or by strengthening their acceptance to the technology. Biogas Companies implementing new projects should first address communities and understand their needs before starting the construction of biogas plants, respecting in that way the requirements of the locals and the need to first secure their acceptance. Energy Communities' role should be further strengthened at a regional level to help communities produce their own energy through autonomous schemes (applying virtual net metering solutions) and also educate the public on the benefits and the critical role biogas plays in energy transition. Lastly, fostering public awareness and acceptance should be realized through the role of media in promoting the technology, and local municipalities in organizing information actions and helping locals contribute to the biogas system through the utilization of the community organic wastes.

Overall, all the recommendations above aim at strengthening the Greek Biogas Innovation System providing solutions to assist the production and expansion of the technology, needed institutional actions to simplify the bureaucratic obstacles, and ways to help local communities be involved in the technology and express their needs.

6.3 Contributions of the Study

This part aims to discuss and clarify this study's contributions in order to provide a clear categorization of important new elements introduced in this research.

6.3.1 Methodology Contributions

Overall, this study was able to contribute with the introduction of a replicable research design through the detailed documentation and reporting of all the methodology actions. Additionally, it employed an agile interview structure with adaptable interview questions to different participants depending on the participant's experience and knowledge. These characteristics provide a basis for similar studies to be performed and the ability to replicate the research in other fields or enhance the existing findings with additional research.

6.3.2 Theoretical Contributions

6.3.2.1 TIS, System Failure, and Stakeholder Participation Frameworks Integration

It is also important to discuss how this study managed to conceptually integrate the theoretical elements of Technological Innovation Systems, Participatory Design, and System failure frameworks to provide a broad analysis of the topic.

As the research topic demanded a complex examination of the characteristics of the Greek Biogas Innovation System, the barriers that the technology faces, and the challenges to include communities in the technology, a simplified TIS analysis with a categorization of the system functions would cover a part of the introduced problem with limitations in its findings. To avoid such limitations and to introduce an additional way that a system is examined and diagnosed, the Technological Innovation Systems theory was utilized to initially identify the characteristics of the system, map the related stakeholders that are directly or indirectly involved, and identify the relations between them. Based on these characteristics this study moved forward with employing the Sytems Failure framework categorizing the systemic failures under certain theoretically conceptualized issues related to infrastructure, capabilities, institutional, interaction, and market failures. This integration of the system failure framework in the TIS framework helped this study broaden its diagnostic capabilities as a clear identification of barriers directly linked with actors able to address them and recommendations for needed changes. As a result, this integration proceeded to understand how the examined Greek Biogas Innovation System failed to follow the targets of production and the growth expected by the Greek Government.

Additionally, this study focused on another important parameter that is substantial to the growth of renewable energy innovation systems and that is the participation of stakeholders. By directly including various different stakeholders as participants in the study it was possible to understand the systemic barriers from the side of the directly and indirectly related stakeholders of the system shedding light on the perspective of stakeholders that could potentially contribute to the system's expansion. In addition, by involving the inclusion aspect of participatory design and the democratization of the system element, communities have been highlighted as important stakeholders with the potential to contribute to the expansion and acceptance of biogas technology.

The integration of these three theoretical foundations in one research eventually helped provide a broad analysis able to identify characteristics, barriers, and stakeholders that might be overlooked under a simpler analysis of the Greek Biogas Innovation System. This aspect provides fruitful ground for future research on the combination of these theories and more in-depth analysis under this context. This approach opens new avenues for understanding and improving the dynamics of renewable energy innovation systems, making it a rich area for continued scholarly exploration and practical application.

6.3.2.2 Climatic Risk as an external barrier

An additional characteristic that was also highlighted in this study which could provide an area for further research was the effect of natural disasters and climatic extreme events on biogas technology growth and development. As previous research has shed light on and validated such a relation this study was able to provide additional information on the issue highlighting this aspect as a problematic element affecting the growth of an innovation system.

In this study, the natural disaster's role emphasized the impact of such events on multiple related barriers in the Greek Biogas Innovation System. Natural disasters were identified as individual barriers leading to infrastructural destructions and disruption of the biogas production processes. Additionally, they magnify other existing problems that affect the growth of biogas technology.

Future research should focus on understanding the relationship between natural disasters and ways to prevent their consequences within a Technological Innovation System. This could provide valuable contributions to policymakers as these events would be considered in the innovation system design and implementation strategies. Moreover, addressing the impacts of natural disasters on biogas technology can help in developing resilient infrastructures that are better equipped to withstand such events, ensuring continuity in biogas production and minimizing potential setbacks.

This approach can help build a robust and adaptive biogas innovation system, contributing to sustainable energy goals despite natural adversities. Integrating these considerations into energy policies can enhance the sector's resilience, promoting a sustainable and secure energy future.

6.3.3 Empirical Findings Contributions

Finally, this study uncovered new empirical findings on the Greek Biogas Innovation system in Greece through the case study in the region of Thessaly. By examining this specific region, the research identified the characteristics of the Greek Biogas Innovation System, the systemic failures, and the challenges to community inclusion. These findings are important as they provide localized insights that can inform targeted policy measures and strategic interventions, enhancing the resilience and effectiveness of biogas technology in Greece which can lead to increased adoption in the country. Understanding these regional dynamics is crucial for developing robust and adaptive changes in the biogas innovation system that can eventually contribute to the country's sustainable energy goals.

6.4 Limitations of the study

Although this case study utilized a robust methodology, it is crucial to acknowledge certain limitations that may have influenced the research results and their interpretation. The limitations of this study include:

Insufficient Sample Size: As the interview sample size included 10 participants due to time constraints and resource constraints, this study's findings lack the generalizability a larger number of participants would bring. This highlights the importance of a larger number of participants in future studies

Lack of previous research studies on the Greek Biogas TIS: The Greek biogas sector is currently considered small and only a few studies have focused on similar topics such as the analysis of the biogas technology under the TIS approach or the identification of barriers to biogas adoption. This presented a challenge to find the available information to validate certain findings and extract information that would help this study.

Geographical Generalizability: The findings from this study, which involve participants from the region of Thessaly may not be generalizable to other Greek regions. This limitation arises due to the unique characteristics of each Greek region that can influence the applicability and relevance of the results outside Thessaly.

Researcher Bias: Given the researcher's extensive experience with the technical aspects of biogas technology, it is possible that this background influences the results of this social study. This may be related to confirmation bias, where the researcher's pre-existing knowledge about biogas technology in Greece may have led to an unconscious emphasis on data that supports certain expectations. To mitigate this potential bias, standardized interview materials and transparent reporting of methodology and findings were applied.

Social desirability bias (Pamela Grimm, 2010): As this study included certain topics of stakeholder participation and community involvement social desirability bias may have influenced participants to provide responses they perceived as more acceptable rather than their true opinions. This was mitigated through the anonymity of their participation and signed informed consent of confidentiality before the interview process.

Time Constraints: The limited time available for conducting this Master's Thesis may have restricted the depth and volume of data collection and analysis.

Resource Constraints: Financial and logistical limitations have impacted the scope of this thesis as it was not possible to conduct extensive field observations and address participants with no virtual access to participate in the interviews.

6.5 Relevance with MSc MOT

The MSc Management of Technology (MOT) program equips students with the needed skills and knowledge to manage technological innovations and aligns with the research presented in this Master Thesis in several key aspects:

Integration of Technology and Management

This thesis focuses on the systemic barriers to the adoption of biogas technology in Greece, on a practical application in managing technology. The MSc MOT program highlights from its beginning the importance of understanding and managing technological innovations at a broad organizational and social level. This research directly contributes to this purpose by examining how biogas technology can be managed, supported, and expanded in the Greek specific economic, regulatory, and social framework.

Interdisciplinary Approach

The research employs a multidisciplinary approach, integrating insights from technology management, environmental science, and social sciences aligning with the MOT program's emphasis on the application of an interdisciplinary approach in order to solve complex technological problems. The analysis of the systemic barriers related to biogas adoption takes into account several technical, economic, marker, institutional, socio-cultural, and environmental components, similar to the methods the MOT program teaches its students to apply.

Innovation Systems and Policy Analysis

This thesis involves the analysis of the Greek Biogas Innovation System through the System Failure and Technological Innovation System frameworks. These frameworks are important for understanding how innovations develop and diffuse within specific contexts and the MOT program includes courses such as Technology Dynamics, Emerging and Breakthrough Technologies, and Technology, Strategy, and Entrepreneurship covering the above frameworks.

Stakeholder and Community Engagement

The thesis emphasizes the role of stakeholder and community engagement in the adoption of biogas technology. These important social aspects represent values that are deeply within the core of the MOT program which highlights the importance of technology management in relation to the social character of innovation.

Policy and Regulatory Environment

The research addresses the impact of the regulatory and policy aspects in the adoption of biogas technology. This highly relates to the MOT program which focuses on the influence of regulations on technological innovation and the importance of understanding the impact of the regulatory environment in technologies.

Sustainability and Renewable Energy

MOT's focus on sustainable technologies and management relates to the scope of this thesis as the main objective is the adoption of renewable technologies, highlighting the importance of energy transition.

Overall, the MSc MOT program prepares engineers to not only understand what technology to use and why but also to analyze how technologies can be adopted in certain contexts and what key elements an engineer should focus on to apply technological solutions efficiently to create positive impact. This thesis from its beginning focused on integrating several of the important lessons taken by the MOT program to approach a problem that requires diverse knowledge in multiple fields to understand it. Through the courses of the MOT program, the author, with existing knowledge in environmental and chemical engineering was able to incorporate the MOT foundations in order to approach the interdisciplinary character this research required.

7 Conclusions

This final part concludes the research findings, interpretations, and discussions, providing an overall understanding of the topic. It summarizes the key findings and their impact while addressing the main research question and the sub-questions. Recommendations are also presented, and future research directions are highlighted, emphasizing the continued relevance of this study.

Focusing on the first sub-question related to the characteristics of the Greek Biogas Innovation System, it can be concluded that the existing system is characterized by a diverse network with complex relations between numerous stakeholders including biogas companies, biomass suppliers such as farmers, municipal authorities, governmental bodies, financial organizations, research organizations, and other several indirectly related stakeholders. This system presents indicators in certain functions such as few entrepreneurial activities, existing knowledge development and diffusion, regulations on innovation guidance, limited market actions apart from the FiTs, problematic mobilization of resources, and growing legitimacy formation actions with the involvement of the Hellenic Biogas Association. The focus of the system is mainly aimed at applying biogas technology for biogas production to electricity transformation with no biomethane production or a regulatory environment to support it.

This system was analyzed based on the case study with stakeholders from the region of Thessaly and using these regional characteristics it was possible to form the image of the Greek Biogas Innovation System in a national context. It is important to acknowledge as a limitation the limited representation of individuals from all the stakeholder categories and regions while a higher number of various participants could provide further information on the characteristics of the Greek Biogas Innovation System. Further research should thus, focus on the identification of the system including a larger sample size with participants from Greek regions with different characteristics.

Moving on to the second sub-question the main objective was to identify the existing system failures related to biogas adoption. This study identified several systemic barriers affecting the system related mainly to infrastructural failures such as the insufficient electricity grid capacity preventing directly the expansion, and institutional failures related to the complex regulatory environment, and the unsuccessful enforcement of regulations on farmers. Interaction failures between stakeholders are mainly fueled by regional competition between companies for feedstock supply, closed networks within the biogas association, or related to hostile relations between local communities and biogas producers. Companies do not have the capabilities to overcome the obstacles of unavailable or unstable feedstock supply while they are also having problems accessing industry information and practices. The public perception and community engagement constitutes also a barrier to biogas adoption with negative media portrayal, local opposition due to environmental concerns, odor issues, and misinformation about biogas technology limiting public acceptance and the involvement of communities.

The third sub-question targeted a specific group of stakeholders, the local communities, and aimed to identify the challenges of community inclusion in the Greek Biogas Innovation

System and solutions to address community needs. To analyze this problem the perceptions of different stakeholders were considered to understand the importance of communities in biogas adoption and the challenges that currently exist. As a result, this study identified problems related to limited knowledge of biogas technology, misconceptions, the absence of observable social benefits from biogas technology, and the lack of cooperation leading to local opposition to biogas projects and the absence of actions to actively participate in biogas production. To address these issues the role of energy communities should be strengthened and information actions should target the clear transfer of information to the public. Future proposed research directions related to this question could be the application of a feasibility study in certain regions such as the Thessaly region in order to evaluate the different ways of addressing these challenges through actions, autonomous schemes, and energy community initiatives. The existing research provides the initial point of focus for future studies to examine different practical tools and practices for community involvement in biogas technology.

Lastly, taking into account all the sub-questions, this study is able to provide an answer to the central research question. Synthesizing the answers of the sub-questions, the findings, and discussions, the growth of the Greek Biogas Innovation System is hindered by a combination of infrastructural, institutional, interaction, and community-related barriers. Barriers such as the outdated and insufficient electricity grid capacity, directly limit the expansion of biogas production while the availability of feedstock affecting productivity is related to the weak regulation enforcement. The institutional environment with regulatory gaps and complex bureaucratic procedures creates obstacles for production and new projects, while interaction barriers characterized by competitive producer relations and weak ties with academia hinder information transfer and knowledge development. Community-related barriers such as the hostility of locals to biogas production, limited knowledge of biogas technology, and misconceptions limit the acceptance and community involvement in biogas projects. Finally, the effect of natural disasters also hinders the innovation system's expansion constituting a problem able to magnify other related issues and can directly hamper the biogas value chain.

Addressing these systemic barriers requires a multidirectional approach. Public investments in the electricity grid, the introduction of biomethane regulations, institutional reforms, the creation of a public body on the system monitoring and information transfer, new training programs for experts, and the active engagement of communities can unlock the potential of the Greek Biogas Innovation System and lead to the expansion of the technology.

These actions are crucial for addressing the identified barriers in the Greek Biogas Innovation System and can help the system move forward to higher production volumes providing a strong system for Greece to foster energy transition and comply with the EU targets.

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8 Appendix

8.1 Appendix A: Participant Documentation

The participant documentation utilized the use of Microsoft Excel as a temporary database of all the participant information. The image below presents an example of the method participants were documented. All names roles, and information of participants have been deleted :

Name	Stakeholder	Role	email	contact	Date Contacted	Tel Contact	Tel Contact	Web Sites	Task
Participant Name	Type of Stakeholder (producer, research organization, etc)	What is their role	active email	Stage of Contact	Last Date of Contact	Tel number	Other tel number	web link	This part has notes on the things mentioned during the contact with the participant. Commends and stage of contact. When to call again and when to arrange the interview
Participant Name	Type of Stakeholder (producer, research organization, etc)	What is their role	active email	Stage of Contact		Tel number	Other tel number	web link	This part has notes on the things mentioned during the contact with the participant. Commends and stage of contact. When to call again and when to arrange the interview
Participant Name	Type of Stakeholder (producer, research organization, etc)	What is their role	active email	Stage of Contact		Tel number	Other tel number	web link	This part has notes on the things mentioned during the contact with the participant. Commends and stage of contact. When to call again and when to arrange the interview
				Green Colour Indicates that the participant agreed to the interview					
				Red means that either the contact details were wrong or a negative					

Figure 6 Participant Documentation Own Image

In addition for contacting participants through email the example email below is presented:

Dear [**Participant Name**],

I hope this email finds you well. My name is [**Researcher Name**], and I am currently pursuing a master's degree in MSc Management of Technology at TU Delft.
I am reaching out to kindly request an interview for my research project.

The focus of my thesis is on the Greek Biogas Innovation System. I am studying the existing socio-technical challenges in the production of Biogas in Greece to identify key points that may require improvement.

This analysis can generate new knowledge and provide valuable insights for the Greek Biogas Industry to upgrade its production capacity.

Additionally, the research is centred in the region of Thessaly, the understanding of the dynamics between the diverse stakeholders, their needs, and their perspectives regarding Biogas.

Considering your interest in this area [**indicate the relation of the participant to biogas**], I would greatly appreciate the opportunity to interview you.

The interview would take approximately one hour, and it would be valuable to have your insights and input on the topic.

If you are available and willing to participate, please let me know your preferred date and time for the interview.

Thank you in advance and I am looking forward to your response.

Kind Regards,
[**Researcher Name**]

Figure 7 Email for contacting participants

These methods are proposed as they provided successful results during the participant contacting and helped maintain a constructed approach in contacting numerous different potential participants.

Continuously modifying the participant list and adding new data and comments was an efficient tool for the researcher to store information and be constantly updated on the contacting process.

8.1.1 Appendix A: Thematic Analysis Method Reporting

The process of the thematic analysis is presented below with figures. Certain information from the participants has been anonymized while no additional information is presented and only the methodology followed is reported.

THEME	SUB-THEME	CODE	QUOTATION
Biogas Innovation System	Stakeholders	Investment organizations	
		Biomass Suppliers	
		Individual Investors (Biogas Companies, Plants)	
		Potential Natural Gas Companies	
		Government Bodies	
		HABIO	
	Stakeholder Relations	Biomass Suppliers and Biogas Investors	
		Biodiesel Producers	
		PV and Wind Turbines	
	System Functions	Commercial Projects and Initiatives	
		Knowledge Development Actions	
		Knowledge Diffusion (Events, Platforms)	
		Innovation Direction	
		Market Formation Actions	
		Resources	
		Legitimacy Formation	
	Regional Factors of Success in Thessaly	Agricultural Residues	
		Investment decisions	
Identification of System Failure	Observed Challenges	Biomas Market Role	
		Knowledge Development	
		Biomass Problems	
		Permiting	
		Digestate waste Problem	
		Farmer Waste Management	
		Strong Network:Biogas Association	
		Limited Information	
		Capability F: University Research	
		Infrastr: Capacity of the electricity network	
	Existing Policies	Strong Inst:Biogas Plants Environmental Regulations	
		Strong Inst:Additional Tarif Due to Energy Crisis	
		Government Policies	
	Needed System Changes	Incentives for Energy biomass Production	
		Access to the electricity network	
		Farmer Regulations	
		ork Capabilities: Implentation of Energy Community Regulation	
		Needed Regulations and Actions for the Biomethane Market	
	Recommendations for an Effective System	troduction of alternative crops, Thessaly revolutionized crops	
		New Technologies	
Inclusion of Other Stakeholders	Perspectives for Inclusion of other Stakeholders	Improvement of Biogas image	
		Use of Community Wastes	
	eds and Issues of Thessaly Communities (types of grou	Farmers Problems	
		Limited Knowledge	
	Challenges to encorouge inclusion	Energy Cost Reduction	
		Food Wastes	
	Existing Tools and policies for community engagemen	Flood Support Mechanisms	
		Social Tariffs	
		Energy Community Engangement	
	Recommendations for cimmunity benefit	Low energy cost	
		Public Investments	

Figure 8 Thematic analysis tables

After the identification of the main themes, codes, and sub-themes in the first interview analysis the workbook containing the identified items was transferred to the next interview analysis with the absence of participant quotes or specific information. These identified items include the main sub-themes and codes identified in order to transfer consistently possible identified codes to the next interview analysis.

As a result, in case a specific code was mentioned again or a specific sub-theme applied also to the views of the next participant, it was added to this part, and new emerging codes were added. Continuing with this logic during the course of all the interviews analysis this method resulted in minimum effort to clear the data after the end of the first analysis and all codes or sub-themes were consistent and error-free.

8.2 Appendix B: Interview Format

This Appendix presents in a detailed way the method the interview material was structured. As explained in Data Collection and Interview Material Structuring the interview material was initially constructed as seen in First Interview Format. Through the feedback of the participants and in order to collect the needed information in a more clear way, it was decided to be changed to revise the interview format presented in Revised Interview Format. Finally, the interview format for the interview with the Flood Victim of Thessaly was changed in order to collect information related to the perspectives of this participant on issues less related with the technical and system aspects of the biogas technology. This format is presented in Flood Victim Interview Format.

8.2.1 Appendix B: First Interview Format

The interview material was divided into 3 different parts with each one representing a part of this study.

8.2.1.1 In English

Christos Kougias, April 2024
MSc Management of Technology TU Delft

Interview questions

Greek Biogas Innovation System and problem identification

Greece has an existing market and industry related to biogas, however there are indications that production targets are not being met while at the same time existing production potential is not being utilised. The objective in this research is first to identify the key stakeholders involved in the Greek Biogas Innovation System and to point out the system's shortcomings that hinder the expansion of the technology. At the same time, there is an environment for the participation and input of other stakeholders (citizens, vulnerable social groups) and communities in the system. It is important to identify the possible ways in which this can be achieved.

To achieve this and enrich our knowledge in these areas we need the views of stakeholders to share their insight into the system, their views on existing issues and their opinion on the inclusion of additional stakeholders in biogas production.

1. **Introduction** (5 min .)
   a. Do you consent to this interview being recorded to better integrate the findings?
   b. Short Introduction.
   c. Do you have any questions before we get started?

2. **Biogas Innovation System in Greece and Thessaly** (15 min.)
   a. From your perspective, how do you recognize the industry around biogas technology? Who is involved in the industry and what is your role?

   b. What is your relationship with these stakeholders?

Figure 9 First Interview Format: English Part 1

In the first part, questions were related to the identification of the systemic functions of the Greek Biogas Innovation System. The participants described their role in the system, their actions, and relations with other actors and additionally provided their knowledge on the TIS functions related to biogas in Thessaly and Greece.

To construct this part of the interview the previous research from Nevzorova, (2022) was used. The author has defined the seven TIS functions in a structured way containing also specific indicators. During the interview construction, it was decided that this arrangement provides the best way for participants to identify the TIS functions and additionally expand on certain characteristics that have already been used in existing literature from other Biogas TIS such as the Russian TIS.

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c. In an innovation system there are multiple actions that help in its development. Regarding biogas, do you recognize any of the following actions and what can you add to it?

Actions in the System	Indicators
Entrepreneurship actions	Commercial projects, experiments, presentations of innovative units
Knowledge Development	Studies, Research Programs, Patents, R & D , scientific publications
Diffusion of Knowledge	Conferences, Platforms, Workshops, Meetings, Partnerships, Joint Projects and Alliances
Guidance of Search	Institutions, Formal Regulations, Laws, Guidelines, Informal Interfaces, Expectations, Promises, Press articles that raise expectations
Market Creation	Tariff Policies, CO2 Taxes, Tax Exemptions, Feed-in Rates, Feed - in - Tariffs, Regulatory Programs, and Incentive Programs
Resource Mobilization	Human resources, Specialists (Experts), Financial resources, Subsidies and Investments through business and government programs, Natural Resources (Availability), General Infrastructure, Education Systems, Supply Infrastructure
Creating Legitimacy	Interest Groups, Lobbying Activities, Media, Promotion of Technology by organizations and governments (awards), Competitions

d. In the area of Thessaly, what is your perspective on biogas production? Which of the above actions is specifically recognized in Thessaly?

Figure 10 First Interview Format: English Part 2

The second part of the interview was centered on the analysis and identification of existing observable problems in the Biogas Innovation System.

Initially, the participants identified the main problems based on the system functions and at a later stage the main regulations related to these problems. At the same time, it was possible to further add their views on these issues and ways that the regulatory framework and the systemic failures could be resolved through specific actions.

Through the work of Klein Woolthuis et al., (2005), on characterizing the four types of system failures the interview questions were mainly related in identifying the existing institutional situation. At the same time as the author's framework centers around the needed policy interventions in order to address the existing system failures, participants were asked to recommend ways to intervene in the existing system and propose changes that could help the system overcome the observed barriers. This method was initially difficult to communicate with the participants and as will be seen in Revised Interview Format it was revised.

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e. What do you think are the factors that helped the region to develop biogas production?

3. **Problems in the biogas innovation system** (20 min.)

   a. What problems do you see in your operations?

   b. What problems do you see in the government policies implemented regarding biogas?

   c. What are the main problems you find in the environment around Biogas based on the system functions that you identified in the previous part?

   d. What are the challenges for a stakeholder in your industry to succeed and contribute to innovative results?

   e. If you could provide a recommendation for policy intervention, where do you think it is now centered who does it involve, and what should have been involved based on your recommendation?

   Infrastructure, Institutions, Partnerships and Connections, Capabilities of technology.

4. **Involvement of Other Stakeholders** (10 min.)

As you may have noticed the inclusion of other groups and community involvement is important in many cases and for many technologies. It can help systems be designed and respond to the needs of its members.

Figure 11 First Interview Format: English Part 3

Finally, the third part of the interview material was based on the inclusion of other stakeholders and the local communities.

Participants shared their knowledge and perspectives on the existing actions and the effectiveness of other stakeholders' engagement in the biogas system. This part was initially constructed based on the Participatory Design approach of democratizing the innovation process and chapter Stakeholder Participation & Participatory Design. As a result, the questions were centered around the perspectives of the directly involved biogas stakeholders regarding community participation and their existing actions to improve the situation. During the interviews, the matter was explained thoroughly based on the researcher's existing knowledge and it was possible for participants to share their thoughts and views.

The last question aimed to identify existing tools and regulations used to help communities be included in the system in order to identify existing actions for community empowerment.

Christos Kougias, April 2024
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In crises such as the disasters in Thessaly, it is evident that the need to support communities energetically through their inclusion and active role is important for the success of the innovation system.

a. How do you perceive the engagement and inclusion of other stakeholders in the biogas innovation system?
b. To what extent do you think that social groups (such as flood victims, or other groups) currently participate indirectly or directly in the system?
c. What are the actions you could take to get them included?
d. What do you think are the regulatory actions on the part of the state to help include these groups?

5. **Conclusion** (5 **min** .)
    a. Do you have contacts who might want to participate in the study?
    b. Is there anything else you'd like to add or additional information you'd like to share about the things we've discussed?

Figure 12 First Interview Format: English Part 4

8.2.1.2 In Greek

For the assistance of the reader, the interview questions are also presented in their intitial form in the Greek language.

Χρήστος Κούγιας, Απρίλιος 2024
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Ερωτήσεις συνέντευξης

Ελληνικό Σύστημα Καινοτομίας Βιοαερίου και εντοπισμός προβλήματος

Η Ελλάδα διαθέτει υπάρχουσα αγορά και βιομηχανία που σχετίζεται με το βιοαέριο, ωστόσο υπάρχουν ενδείξεις ότι οι στόχοι παραγωγής δεν επιτυγχάνονται ενώ ταυτόχρονα δεν αξιοποιείται το υπάρχον δυναμικό παραγωγής. Στόχος αυτής της έρευνας είναι πρώτα να εντοπιστούν οι βασικοί ενδιαφερόμενοι φορείς που εμπλέκονται στο Ελληνικό Σύστημα Καινοτομίας Βιοαερίου και να επισημανθούν οι ελλείψεις του συστήματος που εμποδίζουν την επέκταση της τεχνολογίας. Ταυτόχρονα, υπάρχει ένα περιβάλλον για τη συμμετοχή και τη συμβολή άλλων ενδιαφερομένων (πολίτες, ευάλωτες κοινωνικές ομάδες) και κοινότητες στο σύστημα. Είναι σημαντικό να εντοπιστούν οι πιθανοί τρόποι με τους οποίους μπορεί να επιτευχθεί αυτό.

Για να το επιτύχουμε αυτό και να εμπλουτίσουμε τις γνώσεις μας σε αυτούς τους τομείς χρειαζόμαστε τις απόψεις των ενδιαφερομένων για να μοιραστούν τις απόψεις τους για το σύστημα, τις απόψεις τους για τα υπάρχοντα ζητήματα και τη γνώμη τους για τη συμπερίληψη πρόσθετων ενδιαφερομένων στην παραγωγή βιοαερίου.

1. **Εισαγωγή** (5 λεπτά)
    a. Συμφωνείτε να ηχογραφηθεί αυτή η συνέντευξη για την καλύτερη ενσωμάτωση των ευρημάτων;
    b. Μικρός Εισαγωγή.
    c. Έχετε ερωτήσεις πριν ξεκινήσουμε ;

2. **Σύστημα Καινοτομίας Βιοαερίου στην Ελλάδα και τη Θεσσαλία** (15 λεπτά)
    a. Από τη δική σας οπτική γωνία, πώς αναγνωρίζετε τη βιομηχανία γύρω από την τεχνολογία βιοαερίου; Ποιος ασχολείται με τον κλάδο και ποιος είναι ο ρόλος σας;

Figure 13 First Interview Format: Greek Part 1

b. Ποια είναι η σχέση σας με αυτά τα ενδιαφερόμενα μέρη;

c. Σε ένα σύστημα καινοτομίας υπάρχουν πολλαπλές ενέργειες που βοηθούν στην ανάπτυξή του. Όσον αφορά το βιοαέριο, αναγνωρίζετε κάποια από τις παρακάτω ενέργειες και τι μπορείτε να προσθέσετε σε αυτό;

Ενέργειες στο σύστημα	δείκτες
Δράσεις επιχειρηματικότητας	Εμπορικά έργα, πειράματα, παρουσιάσεις καινοτόμων μονάδων
Ανάπτυξη Γνώσης	Μελέτες, Ερευνητικά Προγράμματα, Διπλώματα Ευρεσιτεχνίας, Ε & Α , επιστημονικές δημοσιεύσεις
Διάχυση της Γνώσης	Συνέδρια, Πλατφόρμες, Εργαστήρια, Συναντήσεις, Συνεργασίες, Κοινά Έργα και Συμμαχίες
Καθοδήγηση αναζήτησης	Θεσμοί, Επίσημοι Κανονισμοί, Νόμοι, Κατευθυντήριες γραμμές, άτυπες διεπαφές, προσδοκίες, υποσχέσεις, άρθρα τύπου που αυξάνουν τις προσδοκίες
Δημιουργία Αγοράς	Τιμολογιακές πολιτικές, φόροι CO2 , φορολογικές απαλλαγές, ποσοστά τροφοδοσίας, τιμολόγια τροφοδοσίας , ρυθμιστικά προγράμματα και προγράμματα κινήτρων
Κινητοποίηση πόρων	Ανθρώπινο δυναμικό, Ειδικοί (Εμπειρογνώμονες), Χρηματοδοτικοί πόροι, επιδοτήσεις και επενδύσεις μέσω επιχειρηματικών και κυβερνητικών προγραμμάτων, Φυσικοί Πόροι (Διαθεσιμότητα), Γενικές Υποδομές, Εκπαιδευτικά Συστήματα, Υποδομές Εφοδιασμού
Δημιουργία Νομιμότητας	Ομάδες Ενδιαφερόντων, Δραστηριότητες Lobbying, ΜΜΕ, Προώθηση Τεχνολογίας από οργανισμούς και κυβερνήσεις (βραβεία), Διαγωνισμοί

Figure 14 First Interview Format: Greek Part 2

d. Στην περιοχή της Θεσσαλίας, ποια είναι η οπτική σας για την παραγωγή βιοαερίου; Ποια από τις παραπάνω ενέργειες αναγνωρίζεται συγκεκριμένα στη Θεσσαλία;

e. Ποιοι πιστεύετε ότι είναι οι παράγοντες που βοήθησαν την περιοχή να αναπτύξει την παραγωγή βιοαερίου;

3. **Προβλήματα στο σύστημα καινοτομίας βιοαερίου** (20 λεπτά)

a. Τι προβλήματα βλέπετε στις λειτουργίες σας;

b. Ποια προβλήματα βλέπετε στις κυβερνητικές πολιτικές που εφαρμόζονται σχετικά με το βιοαέριο;

c. Ποια είναι τα κύρια προβλήματα που βρίσκετε στο περιβάλλον γύρω από το Βιοαέριο με βάση τις λειτουργίες του συστήματος που εντοπίσατε στο προηγούμενο μέρος;

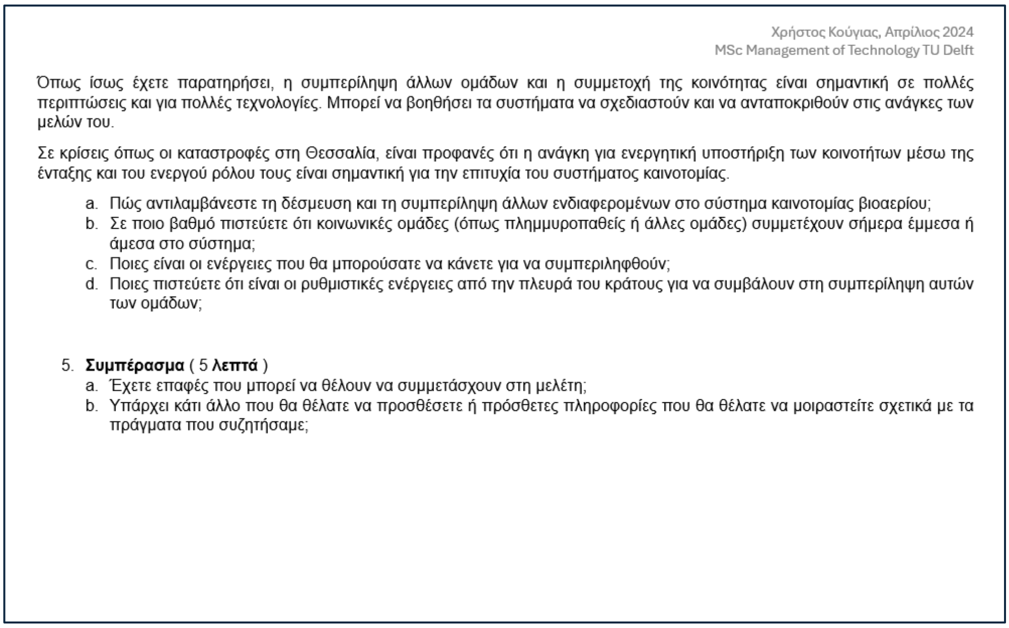
d. Ποιες είναι οι προκλήσεις για έναν ενδιαφερόμενο στον κλάδο σας να πετύχει και να συμβάλει σε καινοτόμα αποτελέσματα;

e. Εάν θα μπορούσατε να υποβάλετε μια σύσταση για παρέμβαση πολιτικής, πού πιστεύετε ότι επικεντρώνεται τώρα σε ποιον εμπλέκεται και τι θα έπρεπε να έχει εμπλακεί με βάση τη σύστασή σας;

Υποδομές, Θεσμοί, Συνεργασίες και Συνδέσεις, Δυνατότητες τεχνολογίας .

4. **Συμμετοχή άλλων ενδιαφερομένων** (10 λεπτά)

Figure 15 First Interview Format: Greek Part 3



Χρήστος Κούγιας, Απρίλιος 2024
MSc Management of Technology TU Delft

Όπως ίσως έχετε παρατηρήσει, η συμπερίληψη άλλων ομάδων και η συμμετοχή της κοινότητας είναι σημαντική σε πολλές περιπτώσεις και για πολλές τεχνολογίες. Μπορεί να βοηθήσει τα συστήματα να σχεδιαστούν και να ανταποκριθούν στις ανάγκες των μελών του.

Σε κρίσεις όπως οι καταστροφές στη Θεσσαλία, είναι προφανές ότι η ανάγκη για ενεργητική υποστήριξη των κοινοτήτων μέσω της ένταξης και του ενεργού ρόλου τους είναι σημαντική για την επιτυχία του συστήματος καινοτομίας.

a. Πώς αντιλαμβάνεστε τη δέσμευση και τη συμπερίληψη άλλων ενδιαφερομένων στο σύστημα καινοτομίας βιοαερίου;
b. Σε ποιο βαθμό πιστεύετε ότι κοινωνικές ομάδες (όπως πλημμυροπαθείς ή άλλες ομάδες) συμμετέχουν σήμερα έμμεσα ή άμεσα στο σύστημα;
c. Ποιες είναι οι ενέργειες που θα μπορούσατε να κάνετε για να συμπεριληφθούν;
d. Ποιες πιστεύετε ότι είναι οι ρυθμιστικές ενέργειες από την πλευρά του κράτους για να συμβάλουν στη συμπερίληψη αυτών των ομάδων;

5. **Συμπέρασμα** (5 **λεπτά**)
a. Έχετε επαφές που μπορεί να θέλουν να συμμετάσχουν στη μελέτη;
b. Υπάρχει κάτι άλλο που θα θέλατε να προσθέσετε ή πρόσθετες πληροφορίες που θα θέλατε να μοιραστείτε σχετικά με τα πράγματα που συζητήσαμε;

Figure 16 First Interview Format: Greek Part 4

8.2.2 Appendix B: Revised Interview Format

8.2.2.1 In English

During the interview process, the questions were modified in order to enhance the effectiveness of the questions and their clarity.

Christos Kougias , April 2024
MSc Management of Technology TU Delft

Interview questions

Greek Biogas Innovation System and problem detection

Biogas in Greece is a growing market with the development of the sector having progressed in recent years. Nevertheless, there are indications that the production targets are not being achieved while at the same time the existing production potential is not being utilized. At the same time, the new production units that are being developed are few in number, while the picture is not clear for other characteristics such as the development of innovative processes, partnerships, infrastructure networks and more generally the factors that may delay the diffusion of technology.

The aim in this research is first to identify the main actors (organizations, institutes, government agencies, groups of individuals) involved in the Greek Biogas Innovation System, the characteristics of this system and to highlight the problems of the system that hinder the expansion of the technology .

At the same time, there is room for the participation and contribution of other parties (citizens, vulnerable social groups, etc.) and communities in the system. It is important to identify the possible ways in which this can be achieved, to understand its needs and to note any actions that are already taking place in the area.

To achieve this and to enrich our knowledge in these areas we need the views of those involved in the field to share their knowledge of the system, their views on existing problems and their opinion on the inclusion of additional groups in biogas production .

1. **Introduction** (5 min .)

a. Do you consent to this interview being recorded/filmed to better integrate the findings?
b. Short Introduction.
c. Do you have any questions before we get started ?

2. **Biogas Innovation System in Greece and Thessaly** (15 min.)

Figure 17 Revised Interview Format: English Part 1

The TIS functions were separated from the initial format they were presented and specific focus was given to each function. This method helped also the interviewer explain to participants related questions, clarifying the information needed in their answers.

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a. From your perspective, how do you recognize the industry around biogas technology?
   i. Which agencies are involved in the industry? (production companies, research organizations, biomass productions, energy communities)
   ii. What is your role?

b. What is your professional relationship with these agencies?

c. In an innovation system there are multiple actions which help in its development. Regarding biogas, do you recognize any of the following actions in the Thessaly region and what can you add to it?
   i. **Entrepreneurship actions related to biogas.**

Entrepreneurship actions
• Commercial projects (Commercial projects) • Presentations of innovative units

   ii. **Development of Knowledge about biogas/biomethane production.**

Knowledge Development
• Studies • Research programs • Patents • R & D • Scientific Publications

   iii. **Actions for knowledge transfer**

Diffusion of Knowledge
• Conferences • Platforms • Workshops, Meetings • Partnerships, Joint Projects and alliances

   iv. **Innovation support actions**

Guiding Innovation
• Institutions, Official Regulations, Guidelines • Informal Interfaces

Figure 18 Revised Interview Format: English Part 2

In addition, a question related to the drivers that accelerated the adoption of Biogas in Thessaly was introduced in order to identify the main initial drivers for the technology expansion.

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• Expectations, Promises, Press articles that raise expectations

v. Actions to create a Market

Create Market
• Pricing Policies, • Carbon Credits , • Tax exemptions, • Feed - in - Tariffs , • Regulatory Programs

vi. Management and resource allocation actions.

Resource Mobilization
• Human resources, Specialists (Experts), • Financial resources, Subsidies and Investments through business and government programs, • Natural Resources (Availability) • General Infrastructure, Education Systems, Supply Infrastructure

vii. Technology Support and Promotion Actions.

Creating Legitimacy
• Interest Groups, Lobbying Activities, • Media, Promotion of Technology by organizations and governments (awards), Competitions

d. What do you think are the factors that helped the region to have developed biogas production?

3. **Problems in the biogas innovation system** (20 min.)

a. What are the main problems you identify in the environment around Biogas based on the characteristics of the system you identified from the previous questions, your activities and the agencies you act on?

Figure 19 Revised Interview Format: English Part 3

The second part of the interview questions was also changed accordingly. An initial question related to the main challenges the participants observed in the system was aimed to identify the first problems that came up related also to the previous;y analyzed TIS. The second question was structured in accordance with the initial question related to the system failures. In this question, existing policies were asked to be identified under the certain four system failures from literature while also points that the regulation should focus on were later asked. To collect information regarding the new entrants in the industry, a third question related to the challenges new entrants face was also introduced.

Finally, an open question related to a biogas Ideal System was providing more creative space for participants. During this question participants in the study were free to propose new changes or even mention again their main arguments, solidifying in that way their views. This question gave the space for new ideas and perspectives to be introduced.

In the last part, participants were asked to provide their perspectives on the inclusion of communities and the support they could provide to these stakeholders in light of the recent events that affected the local communities. The questions were not entirely changed during this part and only changes in the way they were framed helped provide clarity. In this more organized approach, questions were also related to existing actions, views, regulations, and additionally the needs and problems of the community members, related to energy security and the events of the Daniel Storm. The part effectively acted as a method to gather information on the existing actions and perspectives of the stakeholders while existing issues were able to be identified and analyzed during the interviews.

Christos Kougias , April 2024
MSc Management of Technology TU Delft

b. If you could indicate any changes in legislation, where would they be focused and which members of the system would they affect?
   i. Where are the legislations now focused and to whom do they refer? (e.g. biomass allocation legislation, subsidy for biogas production projects, etc.)

Development of Legislation, Actions and projects in the sectors

- **Infrastructure** (e.g. ICT, road networks, electricity networks, other infrastructures)
- **Regulations, Legal Framework** (official provisions or informal rules)
- **Partnerships and Connections** (Relationships between agencies, Possibility of Integration of New Stakeholders)
- **Technology Support Capabilities** (level of knowledge, capabilities to absorb new technological changes)

c. What are the challenges for a stakeholder in your industry to succeed and contribute to innovative outcomes?

d. Based on your views and the Greek environment what an **ideal system** would be like?

4. Participation of Other Social Groups (10 min.)

In designing and developing a robust innovation and technology system, the inclusion of other groups and community participation is important and can have multiple benefits. As a result, including them and understanding the needs of different groups can help systems to be designed and respond to the needs of its members.

In crisis situations such as the disasters in Thessaly, the need to support communities energetically, through their inclusion and their active role, emerges.

a. How do you perceive the participation of citizens and other social groups in the design and implementation of new biogas projects?

b. What are the key needs or concerns you have observed in communities or citizens regarding the use and development of biogas?

Figure 20 Revised Interview Format: English Part 4

Christos Kougias , April 2024
MSc Management of Technology TU Delft

c. What specifically is your role in education, information and collaboration between different groups to ensure sustainability and social acceptance of projects and actions around biogas or the energy transition?

d. What are the possible methods, tools or regulatory provisions that could be used to encourage the active participation of communities and citizens in biogas innovation?

e. What are the potential barriers that communities or citizens may face in taking action on biogas and how can these be addressed through collaboration and innovation?

5. Summary (5 minutes .)

a. Do you have contacts who might want to participate in the survey?
b. Is there anything else you'd like to add or additional information you'd like to share about the things we've discussed?

Thank you!

Figure 21 Revised Interview Format: English Part 5

8.2.2.2 In Greek

For the assistance of the reader, the interview questions are also presented in their revised form in the Greek language.

Χρήστος Κούγιας, Απρίλιος 2024
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Ερωτήσεις συνέντευξης

Ελληνικό Σύστημα Καινοτομίας Βιοαερίου και εντοπισμός προβλημάτων

Το Βιοαέριο στην Ελλάδα αποτελέι μια αναπτυσόμενη αγορά με την ανάπτυξη το κλάδου να έχει σημειώσει εξέλιξη τα τελευταία χρόνια . Παρόλα αυτά υπάρχουν ενδείξεις ότι οι στόχοι παραγωγής δεν επιτυγχάνονται ενώ ταυτόχρονα δεν αξιοποιείται το υπάρχον δυναμικό παραγωγής. Ταυτόχρονα οι νέες παραγωγικές μοναδες που αναπτύσονται είναι λίγες σε αριθμό ενώ δεν είναι ξεκάθαρη η είκόνα για άλλα χαρακτηριστικά όπως η ανάπτυξη καινοτόμων διεργασιών, συνεργασίες, δίκτυα υποδομών και γενιότερα των παραγώντων που μπορεί να καθυστερούν την διάχυση της τεχνολογίας.

Ο στόχος σε αυτή την έρευνα είναι πρώτα να εντοπιστούν οι βασικοί φορείς (οργανισμοί, ινστιτούντα, κρατικοί φορείς, ομάδες ατόμων) που εμπλέκονται στο Ελληνικό Σύστημα Καινοτομίας Βιοαερίου, τα χαρακτηριστικά του συστήματος αυτού και να επισημανθούν τα προβλήματα του συστήματος που εμποδίζουν την επέκταση της τεχνολογίας.

Ταυτόχρονα, υπάρχει χώρος για τη συμμετοχή και τη συμβολή άλλων μερών (πολίτες, ευάλωτες κοινωνικές ομάδες κ.α) και κοινοτήτων στο σύστημα. Είναι σημαντικό να εντοπιστούν οι πιθανοί τρόποι με τους οποίους μπορεί να επιτευχθεί αυτό, να κατανοηθούν οι ανάγκες του αλλά και να σημειωθούν τυχόν ενέργειες που ήδη πραγματοποιούνται στο χώρο.

Για να το πετύχουμε και να εμπλουτίσουμε τις γνώσεις μας σε αυτούς τους τομείς χρειαζόμαστε τις απόψεις εμπλεκομένων στο χώρο για να μοιραστούν τις γνώσεις τους για το σύστημα, τις απόψεις τους για τα υπάρχοντα προβλήματα και τη γνώμη τους σχετικά με τη συμπερίληψη πρόσθετων ομάδων στην παραγωγή βιοαερίου.

1. **Εισαγωγή** (5 λεπτά.)

   a. Συναινείτε στην ηχογράφηση/μαγνητοσκόπηση αυτής της συνέντευξης για καλύτερη ενσωμάτωση των ευρημάτων;
   b. Σύντομη εισαγωγή.
   c. Έχετε ερωτήσεις πριν ξεκινήσουμε;

2. **Σύστημα Καινοτομίας Βιοαερίου στην Ελλάδα και τη Θεσσαλία** (15 λεπτά.)

Figure 22 Revised Interview Format: Greek Part 1

Χρήστος Κούγιας, Απρίλιος 2024
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a. Από τη δική σας οπτική γωνία, πώς αναγνωρίζετε τη βιομηχανία γύρω από την τεχνολογία βιοαερίου;
   i. Ποιοι φορείς εμπλέκονται στον κλάδο; (εταιρείες παραγωγής, ερευνητικοί οργανισμοί, παραγωγέις βιομάζας, ενεργειακές κοινότητες)
   ii. Ποιος είναι ο ρόλος σας;

b. Ποια είναι η επαγγελματική σχέση σας με αυτούς τους φορείς;

c. Σε ένα σύστημα καινοτομίας υπάρχουν πολλαπλές δράσεις οι οποίες βοηθούν στην ανάπτυξη του. Σχετικά με το βιοαέριο, αναγνωρίζετε κάποια από τις παρακάτω δράσεις στην περιοχή της Θεσσαλίας και τι μπορείτε να προσθέσετε σε αυτό;

   i. **Δράσεις επιχειρηματικότητας σχετικά με το βιοαέριο.**

Δράσεις επιχειρηματικότητας
• Εμπορικά έργα (Commercial Projects)
• Παρουσιάσεις καινοτόμων μονάδων

   ii. **Ανάπτυξη Γνώσης σχετικά με την παραγωγή βιοαερίου/βιομεθανίου.**

Ανάπτυξη Γνώσης
• Μελέτες
• Ερευνητικά Προγράμματα
• Διπλώματα ευρεσιτεχνίας
• R&D
• Επιστημονικές δημοσιεύσεις

   iii. **Δράσεις για μεταφορά γνώσης**

Διάχυση Γνώσης
• Συνέδρια
• Πλατφόρμες
• Εργαστήρια, Συνεδριάσεις
• Συνεργασίες, Κοινά Έργα και συμμαχίες

   iv. **Δράσεις υποστήριξης της καινοτομίας**

Καθοδήγηση της Καινοτομίας
• Θεσμοί, Επίσημοι Κανονισμοί, Οδηγίες
• Άτυπες Διεπαφές

Figure 23 Revised Interview Format: Greek Part 2

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- Προσδοκίες, Υποσχέσεις, Άρθρα τύπου που αυξάνουν τις προσδοκίες

v. Δράσεις για τη δημιουργία Αγοράς

Δημιουργία Αγοράς
• Τιμολογιακές Πολιτικές, • Carbon Credits, • Φορολογικές Απαλλαγές, • Ποσοστά τροφοδοσίας, Feed-in-Tariffs, • Ρυθμιστικά Προγράμματα

vi. Δράσεις διαχείρησης και διάθεσης πόρων.

Κινητοποίηση Πόρων
• Ανθρώπινο δυναμικό, Εξειδικευμένοι Ειδικοί (Experts), • Χρηματοοικονομικοί πόροι, Επιδοτήσεις και Επενδύσεις μέσω επιχειρηματικών και κυβερνητικών προγραμμάτων, • Φυσικοί Πόροι (Διαθεσιμότητα) • Γενικές Υποδομές, Εκπαιδευτικά Συστήματα, Υποδομές Ανεφοδιασμού

vii. Δρασεις Υποστήριξης και Πώθησης της τεχνολογίας.

Δημιουργία Νομιμότητας
• Ομάδες Συμφερόντων, Δραστηριότητες Λόμπι, • Μέσα Ενημέρωσης, Προώθηση της Τεχνολογίας από οργανισμούς και κυβερνήσεις (βραβεία), Διαγωνισμοί

d. Ποιοι είναι κατά τη γνώμη σας οι παράγοντες που βοήθησαν την περιοχή να έχει ανεπτυγμένη παραγωγή σε βιοαέριο;

3. **Προβλήματα στο σύστημα καινοτομίας βιοαερίου** (20 λεπτά.)

a. Ποια είναι τα κύρια προβλήματα που εντοπίζετε στο περιβάλλον γύρω από το Βιοαέριο με βάση τα χαρακτηριστικά του συστήματος που αναγνωρίσατε από τις προηγούμενες ερωτήσεις, τις δραστηριότητες σας και τους φορείς που σενεργάζεστε;

Figure 24 Revised Interview Format: Greek Part 3

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b. Εάν μπορούσατε να υποδείξετε κάποιες αλλαγές σε νομοθεσίες, πού θα ήταν επικεντρωμένες και ποια μέλη του συστήματος θα αφορούσαν;
    i. Που είναι τώρα επικεντρωμένες οι νομοθεσίες και σε ποιους αναφέρονται; (πχ νομοθεσίες διαχείρησης βιομαζας, επιχορήγηση έργων παραγωγής βιοαερίου κ.α)

Ανάπτυξη Νομοθεσιών, Δράσεων και έργων στους τομείς¨

- **Υποδομές** (π.χ ICT, οδικά δίκτυα, δίκτυα ηλεκτρισμού, άλλες υποδομές)
- **Κανονισμοί, Νομικό Πλαίσιο** (επίσημες διατάξεις ή ανεπίσημοι κανόνες)
- **Συνεργασίες και Συνδέσεις** (Σχέσεις μεταξύ φορέων, Δυνατότητα Ένταξης Νέων Ενδιαφερόμενων)
- **Δυνατότητες Υποστήριξης της Τεχνολογίας** (επίπεδο γνώσης, δυναντότητες απορρόφησης νέων τεχνολογικών αλλαγών)

c. Ποιες είναι οι προκλήσεις για έναν ενδιαφερόμενο στον κλάδο σας να πετύχει και να συμβάλει σε καινοτόμα αποτελέσματα;

d. Πώς θα ήταν με βάση την άποψη σας και με βάση την ελληνική πραγματικότητα και τα προβλήματα που παρατηρείτε ένα **ιδανικό σύστημα** γύρω από το βιοαέριο;

4. **Συμμετοχή Άλλων Κοινωνικών Ομάδων** (10 λεπτά.)

Στα πλαίσια σχεδίασης και ανάπτυξης ενός ισχυρού συστήματος καινοτομίας και τεχνολογίας, η συμπερίληψη και άλλων ομάδων και η συμμετοχή της κοινότητας είναι σημαντική και μπορεί να έχει πολλαπλά οφέλη. Σαν αποτέλεσμα η συμπερίληψη τους και η κατανόηση των αναγκών διάφορων ομάδων μπορεί να βοηθήσει τα συστήματα να σχεδιαστούν και να ανταποκρίνονται στις ανάγκες των μελών του.

Σε καταστάσεις κρίσης όπως οι καταστροφές στη Θεσσαλία αναδεικνύεται η ανάγκη για στήριξη των κοινοτήτων ενεργειακά, μέσα από την συμπερίληψη τους και τον ενεργό τους ρόλο.

a. Πώς αντιλαμβάνεστε τη συμμετοχή των πολιτών και άλλων κοινωνικών ομάδων στο σχεδιασμό και την υλοποίηση νέων έργων βιοαερίου;

Figure 25 Revised Interview Format: Greek Part 4

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b. Ποιες είναι οι βασικές ανάγκες ή ανησυχίες που έχετε παρατηρήσει στις κοινότητες ή τους πολίτες σχετικά με τη χρήση και την ανάπτυξη του βιοαερίου;

c. Ποιος είναι συγκεκριμένα ο ρόλος σας στην εκπαίδευση, ενημέρωση και τη συνεργασία μεταξύ διαφορετικών ομάδων για τη διασφάλιση της βιωσιμότητας και της κοινωνικής αποδοχής των έργων και δράσεων γύρω από το βιοαέριο ή την ενεργειακή μετάβαση;

d. Ποιες είναι οι πιθανές μεθόδοι, εργαλείαή ρυθμιστικές διατάξεις που θα μπορούσαν να χρησιμοποιηθούν για να ενθαρρυνθεί η ενεργή συμμετοχή των κοινοτήτων και των πολιτών στην καινοτομία βιοαερίου;

e. Ποια είναι τα πιθανά εμπόδια που μπορεί να αντιμετωπίσουν οι κοινότητες ή οι πολίτες στην ανάληψη ενεργειών στον τομέα του βιοαερίου και πώς μπορούν αυτά να αντιμετωπιστούν μέσω της συνεργασίας και της καινοτομίας;

5. **Σύνοψη** (5 λεπτά.)
a. Έχετε επαφές που μπορεί να θέλουν να συμμετάσχουν στην έρευνα;
b. Υπάρχει κάτι άλλο που θα θέλατε να προσθέσετε ή επιπλέον πληροφορίες που θα θέλατε να μοιραστείτε σχετικά με τα πράγματα που συζητήσαμε;

Σας Ευχαριστώ!

Figure 26 Revised Interview Format: Greek Part 5

8.2.3 Appendix B: Flood Victim Interview Format

8.2.3.1 In English

As the interviews with members of Thessaly communities affected by the disasters of the storm would have a different center of discussion the interview material was decided to change.

The interview questions were constructed so that the biogas technology can be intitially explained along with the objective of the study. Next, the effects of the storm were also asked in order to collect information on the needs of Thessaly individuals and communities while the technology problems and benefits retrieved from the ongoing data analysis of the previous interviews were introduced.

Questions were also constructed based on the Suboticki et al., (2023), regarding the engagement opportunities. In this way it was possible to propose certain ways of community engagement and collect the participant's perspectives.

As the analysis of collected data was parallel to the interview material certain recommendations and needs gathered from previous interviews were addressed for validation. This way it was possible to compare the perspectives related to inclusion between active biogas stakeholders and community members.

The interview questions are presented below:

Christos Kougias , April 2024
MSc Management of Technology TU Delft

Interview questions

Greek Biogas Innovation System and problem detection

Biogas in Greece is a growing market with the development of the sector having progressed in recent years. Nevertheless, there are indications that the production targets are not being achieved while at the same time the existing production potential is not being utilized. At the same time, the new production units that are being developed are few in number, while the picture is not clear for other characteristics such as the development of innovative processes, partnerships, infrastructure networks and more generally the factors that may delay the diffusion of technology.

The aim in this research is first to identify the main actors (organizations, institutes, government agencies, groups of individuals) involved in the Greek Biogas Innovation System, the characteristics of this system and to highlight the problems of the system that hinder the expansion of the technology .

At the same time, there is room for the participation and contribution of other parties (citizens, vulnerable social groups, etc.) and communities in the system. It is important to identify the possible ways in which this can be achieved, to understand its needs and to note any actions that are already taking place in the area.

To achieve this and to enrich our knowledge in these areas we need the views of those involved in the field to share their knowledge of the system, their views on existing problems and their opinion on the inclusion of additional groups in biogas production .

1. **Introduction** (5 min .)

   a. Do you consent to this interview being recorded/filmed to better integrate the findings?
   b. Short Introduction.
   c. Do you have any questions before we get started?

Figure 27 Flood Victim Interview Format: English Part 1

Christos Kougias , April 2024
MSc Management of Technology TU Delft

2. **Experiences and Perceptions** (5 min.)

Daniel Storm:

a) The flood-affected communities of Thessaly suffered from the storm Daniel in September 2023. What were the effects on you and what situation are you in now?
b) What are actions taken by the state?

Biogas:

c) What is your opinion on biogas technology and how do you think it can benefit a flood affected community?
d) Do you have experience or knowledge of past or current biogas projects in your area?
e) **Examples:** Let's talk about some examples that have to do with the social acceptance of this technology. Common problems are:

- **Lack of incentives:** The positives of biogas technology such as energy production, environmental benefits and energy cost reduction are not visible to residents. Does this bother you?
- **Odor:** Biogas units smell quite a bit. Would you mind having a unit near your area that has this issue?
- **Plant Residues:** Biogas plants produce some residues which are however soil soil-improving. Communities usually reject them. If you knew the positive benefits of this by-product would you be positive about its use by community members for agricultural crops?

3. **Participation and Impact** (5 min.)

a) How do you think that the flood-prone communities of Thessaly can be more involved in the planning and implementation of biogas projects?
How could this be done:

- Participating in decision-making and focusing on the needs of the community - **without an active role and potential profits**
- Unit Creation - **with an active role and potential earnings**
- Participation through Energy Communities - **with an indirect role and potential profits**

Figure 28 Flood Victim Interview Format: English Part 2

Christos Kougias , April 2024
MSc Management of Technology TU Delft

- Participation among various community groups - **with an active role but not certain motivations**

b) Are there specific concerns or needs that you have noticed in your community that should be addressed?

c) What do you think is the main need if there is the prospect of your participation (e.g. **low energy costs, helping flood-affected communities, environmental benefits, monetary benefit**)

4. **Suggestions for Future Actions** (5 min.)

a) What suggestions do you have for enhancing the active participation of flood affected communities and individuals in biogas development?

b) Could you suggest some specific actions or policies that would improve the situation?

5. **Summary** (5 minutes .)

a. Do you have contacts who might want to participate in the survey?
b. Is there anything else you'd like to add or additional information you'd like to share about the things we've discussed?

Thank you!

Figure 29 Flood Victim Interview Format: English Part 3

8.2.3.2 In Greek

For the assistance of the reader, the interview questions are also presented in their intitial form in the Greek language.

Χρήστος Κούγιας, Απρίλιος 2024
MSc Management of Technology TU Delft

Ερωτήσεις συνέντευξης

Ελληνικό Σύστημα Καινοτομίας Βιοαερίου και εντοπισμός προβλημάτων

Το Βιοαέριο στην Ελλάδα αποτελεί μια αναπτυσόμενη αγορά με την ανάπτυξη το κλάδου να έχει σημειώσει εξέλιξη τα τελευταία χρόνια . Παρόλα αυτά υπάρχουν ενδείξεις ότι οι στόχοι παραγωγής δεν επιτυγχάνονται ενώ ταυτόχρονα δεν αξιοποιείται το υπάρχον δυναμικό παραγωγής. Ταυτόχρονα οι νέες παραγωγικές μοναδες που αναπτύσονται είναι λίγες σε αριθμό ενώ δεν είναι ξεκάθαρη η είκόνα για άλλα χαρακτηριστικά όπως η ανάπτυξη καινοτόμων διεργασιών, συνεργασίες, δίκτυα υποδομών και γενιότερα των παραγώντων που μπορεί να καθυστερούν την διάχυση της τεχνολογίας.

Ο στόχος σε αυτή την έρευνα είναι πρώτα να εντοπιστούν οι βασικοί φορείς (οργανισμοί, ινστιτούντα, κρατικοί φορείς, ομάδες ατόμων) που εμπλέκονται στο Ελληνικό Σύστημα Καινοτομίας Βιοαερίου, τα χαρακτηριστικά του συστήματος αυτού και να επισημανθούν τα προβλήματα του συστήματος που εμποδίζουν την επέκταση της τεχνολογίας.

Ταυτόχρονα, υπάρχει χώρος για τη συμμετοχή και τη συμβολή άλλων μερών (πολίτες, ευάλωτες κοινωνικές ομάδες κ.α) και κοινοτήτων στο σύστημα. Είναι σημαντικό να εντοπιστούν οι πιθανοί τρόποι με τους οποίους μπορεί να επιτευχθεί αυτό, να κατανοηθούν οι ανάγκες του αλλά και να σημειωθούν τυχόν ενέργειες που ήδη πραγματοποιούνται στο χώρο.

Για να το πετύχουμε και να εμπλουτίσουμε τις γνώσεις μας σε αυτούς τους τομείς χρειαζόμαστε τις απόψεις εμπλεκομένων στο χώρο για να μοιραστούν τις γνώσεις τους για το σύστημα, τις απόψεις τους για τα υπάρχοντα προβλήματα και τη γνώμη τους σχετικά με τη συμπερίληψη πρόσθετων ομάδων στην παραγωγή βιοαερίου.

1. **Εισαγωγή** (5 λεπτά.)

   a. Συναινείτε στην ηχογράφηση/μαγνητοσκόπηση αυτής της συνέντευξης για καλύτερη ενσωμάτωση των ευρημάτων;
   b. Σύντομη εισαγωγή.
   c. Έχετε ερωτήσεις πριν ξεκινήσουμε;

2. **Εμπειρίες και Αντιλήψεις** (5 λεπτά.)

Figure 30 Flood Victim Interview Format: Greek Part 1

Χρήστος Κούγιας, Απρίλιος 2024
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Κακοκαιρία Ντάνιελ:

a) Οι πλημυροπαθείς κοινότητες της Θεσσαλίας υπέφεραν από την κακοκαιρία Daniel το Σεπτέμβριο το 2023. Ποιες ηταν οι επιπτώσεις σε εσάς καις σε τι κατάσταση βρίσκεστε τώρα;
b) Ποιες είναι ενέργειες που λήφθηκαν από την πολιτεία;

Βιοαέριο:

c) Ποια είναι η γνώμη σας για την τεχνολογία του βιοαερίου και πώς πιστεύετε ότι αυτή μπορεί να ωφελήσει μια κοινότητα που έχει πληγεί από πλυμήρες;
d) Έχετε εμπειρία ή γνώση για προηγούμενα ή τρέχοντα έργα βιοαερίου στην περιοχή σας;
e) **Παραγείγματα:** Ας πούμε σχετικά με κάποια παραδείγματα που έχουν να κάνουν με την κοινωνική αποδοχή αυτής της τεχνολογίας. Συνήθη προβλήματα είναι:

   - **Απουσία κινήτρων:** Τα θετικά της τεχνολογίας του βιοαερίου όπως παραγωγή ενέργειας, περιβαλλοντικά οφέλη και μείωση κόστους ενέργειας δεν είναι ορατά από τους κατοίκους. Σας ενοχλέι αυτό;
   - **Οσμή:** Οι μονάδες βιοαερίου μυρίζουν αρκετα. Θα σας πείραζε να υπάρχει μια μονάδα κοντά στην περιοχή σας η οποία να έχει αυτό το ζήτημα;
   - **Υπολείματα Μονάδων:** Οι μονάδες βιοαερίου παράγουν κάποια υπολείματα που είναι όμως εδαφοβελτιωτικα. Οι κοινότητες συνήθως τα απορίπτουν. Εάν γνωρίζατε τα θετικά οφέλη αυτού του παράγωγου θα είσασταν θετική στη χρήση του από μελη της κοινότητας για αγροτικές καλιέργιες;

3. **Συμμετοχή και Αντίκτυπος** (5 λεπτά.)

a) Πώς πιστεύετε ότι οι πλημυροπαθείς κοινότητες της Θεσσαλίας μπορούν να εμπλακούν περισσότερο στον σχεδιασμό και την υλοποίηση έργων βιοαερίου;
Πως θα μπορούσε να γίνει αυτό:
   - Συμμετοχή στη λήψη αποφάσεων και εστίαση τις ανάγκες της κοινότητας-**χωρίς ενεργό ρόλο και πιθανά κέρδη**
   - Δημιουργία Μονάδας-**με ενεργό ρόλο και πιθανά κέρδη**
   - Συμμετοχή μέσα από Ενεργειακές Κοινότητες- **με έμμεσο ρόλο και πιθανά κέρδη**
   - Συμμετοχή μεσα από διάφορες κοινοτικές ομάδες-**με ενεργό ρόλο αλλά όχι σίγουρα κίνητρα**

Figure 31 Flood Victim Interview Format: Greek Part 2

Χρήστος Κούγιας, Απρίλιος 2024
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b) Υπάρχουν συγκεκριμένες ανησυχίες ή ανάγκες που έχετε αντιληφθεί στην κοινότητά σας που θα έπρεπε να ληφθούν υπόψη;

c) Ποια είναι κατά τη γνώμη σας η κυριότερη ανάγκη εφόσον υπάρχει η προοπτική τη συμμετοχής σας (π.χ **χαμηλο κοστος ενέργειας, βοήθηση πλυμηροπαθών κοινοτήτων, περιβαλλοντικά οφέλη, χρηματικό όφελος**)

4. **Προτάσεις για Μελλοντικές Δράσεις** (5 λεπτά.)

a) Ποιες προτάσεις έχετε για την ενίσχυση της ενεργού συμμετοχής των πλημυροπαθών κοινοτήτων και ατόμων στην ανάπτυξη του βιοαερίου;

b) Θα μπορούσατε να προτείνετε κάποιες συγκεκριμένες δράσεις ή πολιτικές που θα βελτιώσουν την κατάσταση;

5. **Σύνοψη** (5 λεπτά.)

a. Έχετε επαφές που μπορεί να θέλουν να συμμετάσχουν στην έρευνα;
b. Υπάρχει κάτι άλλο που θα θέλατε να προσθέσετε ή επιπλέον πληροφορίες που θα θέλατε να μοιραστείτε σχετικά με τα πράγματα που συζητήσαμε;

Σας Ευχαριστώ!

Figure 32 Flood Victim Interview Format: Greek Part 3