

DELFT UNIVERSITY OF TECHNOLOGY

Governing and scaling aquathermal energy system
innovation in the Fryslân region



BY HADEER RAMDAN

STUDENT NUMBER: 5496772

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Graduation-Committee:

Dr. L.M. Kamp	First supervisor & Chair	Delft University of Technology
Dr. B.J. Pearce	Second Supervisor	Delft University of Technology
Dr. N. Mohlakoana	Advisor & Daily Supervisor	Delft University of Technology
Prof. Dr. T. Hoppe	External Supervisor	University of Twente

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EXECUTIVE SUMMARY

This study, titled "Governing and Scaling Aquathermal Energy System Innovation in the Fryslân Region," investigates the niche growth of surface water aquathermal energy (AE) in rural Friesland. The study uses the Strategic Niche Management (SNM) and Multi-Level Perspective (MLP) frameworks to investigate the multiple elements impacting AE's growth and potential for scalability. The fundamental goal of this research is to find and recommend measures that will allow the widespread adoption of AE, thereby significantly contributing to Friesland's sustainable energy landscape.

The approach used for this study was multidimensional. It began with a thorough review of the literature to situate AE within existing academic knowledge. This was followed by an analysis of cases from regions such as Denmark, Belgium, and Sweden, which have similar geographical and regulatory settings and can provide useful lessons for Friesland. Furthermore, semi-structured interviews were performed with 14 stakeholders, including local project leaders, policymakers, and international experts, to get qualitative insights into the practical implementation, problems, and opportunities related with AE in this rural environment.

The findings show that Friesland's AE niche is now being created by community-driven projects, with initiatives such as Warm Heeg illustrating how AE may be integrated into larger sustainability frameworks. Despite these encouraging developments, the niche is still in its early stages, with most applications limited to individual residences or small community installations, indicating a need to scale these systems to satisfy regional energy demands.

From an MLP viewpoint, the study emphasizes the impact of landscape elements such as climate change legislation and global demand for energy security, which are creating opportunities for AE. However, the current political atmosphere, which is shifting away from sustainability measures, poses a substantial barrier to the expansion of this niche. The current heating system in Friesland, which is primarily based on fossil fuels, presents both economic and infrastructure hurdles for AE adoption. High connection and installation costs, combined with the requirement for new or modified infrastructure, are the key hurdles. At the niche level, AE is viewed as a possible long-term option, but its incorporation into the current system is slow, demanding intentional interventions to overcome these barriers.

The study emphasizes the importance of shared vision and stakeholder participation in Friesland by utilizing SNM principles. Local energy cooperatives and municipalities have set ambitious targets for AE, focusing on community involvement and ownership to create trust and acceptance. Pilot initiatives, such as ones in Heeg, have provided critical learning opportunities for technology and tactics. Network building among varied stakeholders has facilitated knowledge sharing and collaborative project management, ensuring that goals and expectations are aligned.

The global learnings from AE projects in other locations serve as a road map for Friesland. Key takeaways include the importance of strong stakeholder collaboration, the creation of clear policy frameworks that promote rather than inhibit AE, and the value of public involvement in driving acceptability. Hybrid systems that integrate AE with other renewables provide a model for efficiency and resilience, which is especially essential given Friesland's climate circumstances.

Despite the stated constraints, such as high initial costs and legal difficulties, opportunities exist through community engagement, creative financing such as crowdfunding, and the implementation of worldwide best practices suited to local situations. Friesland has great AE potential due to its enormous water supplies and commitment to sustainability.

The study indicates that AE's growth in Friesland is driven by a complex interplay of technological, economic, environmental, and social factors. While there are significant hurdles, the region's commitment to sustainability, strategic stakeholder collaboration, and policy advocacy may lead the way for scaling AE. The recommendations include developing uniform and supportive regulatory settings, improving public education to promote acceptance, and performing additional research to assess environmental impacts and refine economic models.

Academically, this study contributes to the discussion on renewable energy transitions in rural areas by offering specific insights into how SNM and MLP might lead the scale of niche technologies such as AE. It provides a practical case study that complements theoretical frameworks with real-world applications, adding to broader academic and policy discussions about sustainable energy transitions.

The study also underlines the importance of constant learning and adaptability in the AE niche. Iterative processes witnessed in pilot projects in Friesland provide useful lessons on both the technical and social elements of AE implementation. This understanding is critical for overcoming the practical hurdles of incorporating AE into existing heating systems, particularly in older buildings with insulation and compatibility issues.

Furthermore, the study calls for a more inclusive approach to stakeholder involvement. By broadening the conversation to include more varied perspectives, such as small enterprises, environmental groups, and under-represented community members, Friesland can build a stronger foundation of support for AE systems. This inclusivity can lead to more specialized solutions that take into account local demands and environmental implications, instilling a sense of ownership and responsibility for the energy transition.

On the policy front, the report advocates for regulatory coherence at the regional and national levels. This would streamline the approval processes for AE projects, lowering the time and regulatory barriers that currently exist. It also suggests the creation of financial structures specifically suited for rural settings, when typical funding models may not be sufficient. This might include more flexible subsidies, tax breaks, or even the creation of regional funds specifically for renewable energy projects.

Finally, the academic merit of this study stems from its use of theoretical frameworks such as SNM and MLP in a real-world, rural environment. It not only verifies but also expands upon these notions, providing actual evidence on how niche innovations can challenge and finally integrate into established systems. This study facilitates future research in similar circumstances around the world, prompting a rethinking of how rural communities might lead in sustainable energy transitions with the correct assistance and strategies.

In conclusion, the study presents an overview of the current situation and prospective future of AE in Friesland, making both practical recommendations for stakeholders and adding to the scholarly discourse on energy transitions. It emphasizes the need of community, policy, and technological collaboration in scaling breakthrough energy solutions in areas usually viewed as difficult for such advancements.

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1

INTRODUCTION

The global transition to sustainable energy solutions goes beyond power generation. Heating and cooling our houses and buildings contribute significantly to greenhouse gas emissions. Aquathermal Energy Systems (AE) have surfaced as a potentially transformative technology that can effectively tackle the mounting apprehensions associated with conventional heating and cooling systems (Goossens et al., 2021). Utilising the power of water for sustainable heating is gaining popularity worldwide (Goossens et al., 2021).

Unlike traditional systems that rely on fossil fuels or deep underground aquifers, surface water AE makes efficient use of easily available surface water resources like lakes, canals, rivers, and even the sea (Goossens et al., 2021). These vast bodies of water have natural thermal capacity that is just ready to be harnessed. During the colder months, surface water AE systems activate. Water is taken from various sources and sent via a heat exchanger. This innovative piece of technology serves as the system's heart, harnessing the thermal energy contained in the water. The captured heat is then dispersed through a network of insulated pipes, similar to district heating systems, providing warmth to houses and buildings (Goossens et al., 2021).

During warmer months, the system might be reversed. It functions as a natural air conditioner by reintroducing heat into the surface water. This sustainable cooling alternative reduces the need for conventional air conditioning equipment, which contributes to peak energy demand (Goossens et al., 2021).

Surface water AE has the potential to provide enormous benefits, especially in locations with sufficient surface water. This technology provides a comprehensive strategy for sustainability. First, it considerably decreases dependency on fossil fuels for heating and cooling, resulting in cleaner air and a lower carbon footprint (Goossens et al., 2021), (Sea, 2023). Second, by using a renewable resource, surface water AE contributes to energy independence and diversification (Sea, 2023).

Aquathermal energy refers to the extraction, storage, and transport of heat from water (Sea, 2023). By looking at Figure 1 below, we can understand how aquathermal energy systems work. 1. During the summer, the sun heats the surface water. The heated water is kept in a heat-cold storage facility. 2. During the winter, heat is removed from the water. A collective heat pump raises this heat, along with the stored hot water, to a temperature suitable for heating. 3. Water from the collective heat pump is distributed to homes and buildings via a heat network. The cooled water is stored in the heat-cold storage to cool buildings throughout the summer (Sea, 2023), (Goossens et al., 2021).

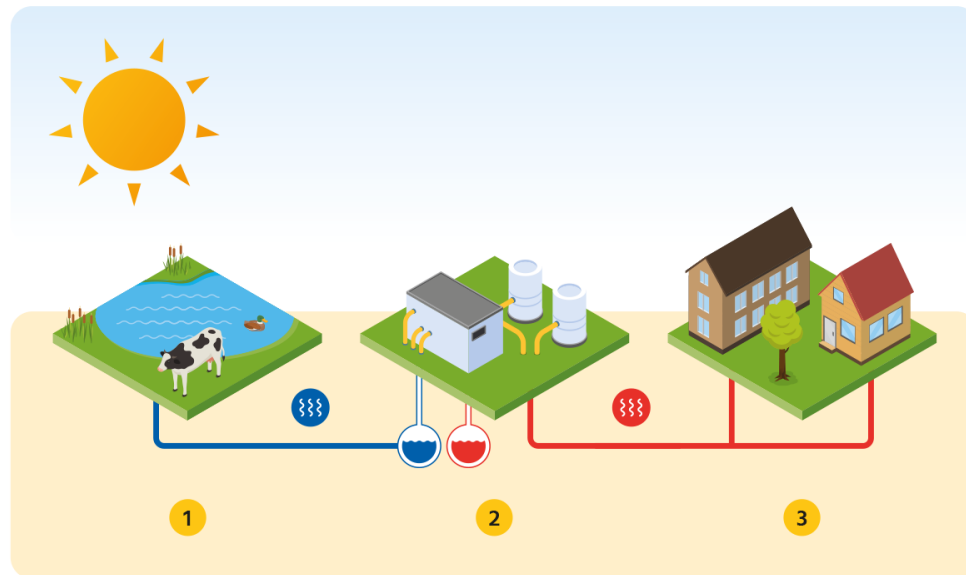


Figure 1: Aquathermia Demo, (Sea, 2023)

Although as a potential renewable energy source for heating and cooling, there are certain obstacles preventing aquathermal energy from being widely used. Heat pumps can cause noise pollution in residential areas, therefore it's important to install and insulate them carefully (Goossens et al., 2021). Furthermore, the technology's application is restricted in some areas by its reliance on adequate surface water resources. The viability of aquathermal systems can be affected by other considerations even in suitable sites. First and foremost, the distance between the buildings and the water source is important. Lower temperature (LT) heat is used in aquathermal energy, therefore heat loss during transit becomes a major concern (Goossens et al., 2021). This raises an additional problem with the current infrastructure is that many buildings are not insulated well enough to effectively use the lower temperature heat that aquathermal systems deliver. As a result newer, well-insulated buildings are better prospects for aquathermal technology since they can more effectively use the lower temperature heat (Goossens et al., 2021). In addition a district heating system is needed to distribute the extracted heat to buildings (Goossens et al., 2021). It may be necessary to install completely new systems in some situations, but it may be more practical to locate the aquathermal project close to an already-existing infrastructure in other scenarios (Goossens et al., 2021). These limitations, along with the high cost of titanium heat exchangers needed to prevent micro bacterial deterioration, emphasize the need for technological advancements to address noise, reduce costs, and explore alternative materials (Goossens et al., 2021). As a result when developing and implementing aquathermal energy systems, all these limitations should be taken into account and addressed properly.

The Green Deal Aquathermia is an example of a collaborative action for a sustainable future in the Netherlands. This was rather a signed agreement between a diverse group of stakeholders in the Netherlands (Deals, 2019). Key players included government ministries like the Ministry of Economic Affairs and Climate, the Ministry of Infrastructure and Water Management, and the Ministry of the Interior and Kingdom Relations. Regional water management expertise came from The Union of Water Boards, while the Association of Dutch Municipalities (VNG) represented local governments. Research institutions like Deltares, Stichting Applied Research Water Management (STOWA), KWR, and Erasmus University Rotterdam provided valuable knowledge. Water Board Brabantse Delta, Water Board Aa en Maas, Brabant Water, and the Rijkswaterstaat water authority all brought their practical experience to the table. The private sector was well represented by Netbeheer Nederland (grid operators), Syntral (engineering), Invest NL (investment), NWB Bank (financing), Vewin (energy company), IF Technology (aquathermia specialists), and Balance (consultancy) (Deals, 2019). With this impressive array of government agencies, water authorities, research institutions, and private companies all working together, the Green Deal Aquathermia fostered a powerful

platform for knowledge exchange and collaboration (Deals, 2019). They tackled crucial aspects like developing a research and development strategy, identifying promising new projects across provinces like Friesland, Gelderland, and South Holland, and sharing best practices for managing and financing these systems. This collaborative effort has significantly increased public awareness of aquathermia (Deals, 2019), leading to its integration into new construction projects and recognition by the government as a key element of their future energy plans, with an ambitious goal of heating and cooling over 200,000 homes by 2030 (Deals, 2019)

In Friesland, this approach is known as *Wetterwaarmte* (Fryslan, 2022). The Province of Friesland initiated the establishment of *Wetterwaarmte*, motivated by the desire to develop Friesland into the leading aquathermy province in the Netherlands (van de Witte, 2023). This is not a formal policy or programme, but rather a collaborative effort led by a committed working group. The working group combines expertise from the Province, *Wetterskip Fryslân*, four municipalities (de Fryske Marren, Leeuwarden, Súdwest-Fryslân, and Terschelling), and a programme secretary from *Waterprof*, an organisation specialising in programme management for water, agriculture, and energy (van de Witte, 2023). All the partners involved in the *Wetterwaarmte* project are demonstrated in Figure 2. Their common goal, expressed in *Wetterwaarmte*, is to speed up the transition of Friesland to sustainable heating by encouraging the widespread use of district heating networks and aquathermy systems in buildings, supporting local projects that investigate this technology, and encouraging a sense of local ownership throughout the process. *Wetterwaarmte* is a framework for cooperation and action that propels Friesland towards an aquathermy-powered future (van de Witte, 2023).

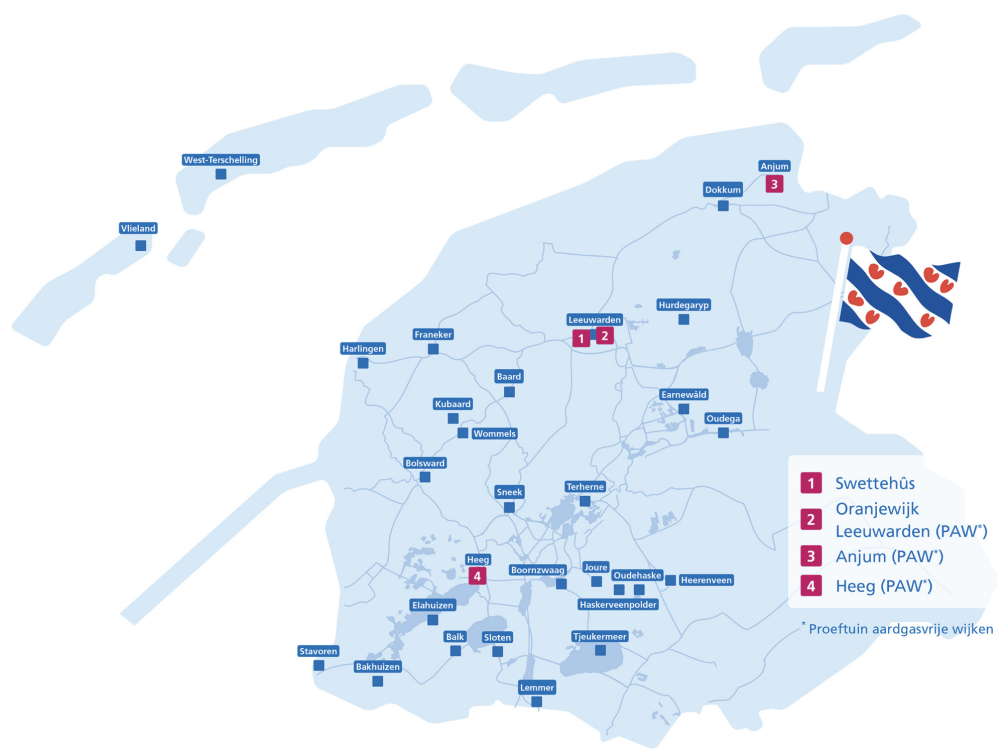


Figure 2: An overview of the *Wetterwaarmte* partners in Friesland (Fremouw, 2024).

Unlike typical aquathermal energy systems (AE) that rely on aquifers, *Wetterwaarmte* utilises Friesland's enormous surface water resources. Estimates indicate that this strategy has the potential to meet a considerable amount of the region's heating needs, reducing dependency on fossil fuels and contributing to a cleaner energy future (van de Witte, 2023), (Fryslan, 2022). However, establishing and scaling surface water AE in a rural area brings unique problems when compared to aquifer-based systems. *Wetterwaarmte* is a possible alternative for rural communities looking to migrate to sustainable renewable energy sources, but questions

remain about its large-scale adoption and the unique governance considerations it provides (Fryslan, 2022), (van de Witte, 2023).

This research will explore how stakeholders within the *Wetterwaarmte* niche can leverage knowledge sharing, network building, and policy advocacy to promote wider adoption of surface water AE. Ultimately, this research aims to contribute to a successful transition towards a sustainable energy future for Friesland, fuelled by the collective power of *Wetterwaarmte* and a strategically managed socio-technical system

1.1 Knowledge gap in the academic literature

While some insights into aquathermal energy (AE) systems and district heating grids already exists (Gürsan et al., 2024), (Goossens et al., 2021), (Peters, 2022), (van der Roest et al., 2021), there is still a significant knowledge gap about their implementation in rural settings (Kaphengst & Velten, 2014), (van 't Westende T, 2021)). Where (Goossens et al., 2021) identified technical and social requirements for successful aquathermal energy implementation, highlighting the benefits of AE systems in the region of Utrecht. However also showing that Utrechtse Heuvelrug faces limitations due to water scarcity, dispersed housing, and insulation. It also mentions that both ecological impacts and public perception should be researched. Another research (van de Witte, 2023) conducted in Friesland, indicated that aquathermy is a solution that has great potential for the province of Friesland and highlighted the need to research the governance-related obstacles that stakeholders must get beyond in order to finish the initiative in Friesland and provide this knowledge.

Accordingly there is currently no research done utilizing the Multi-Level Perspective (MLP) and Strategic Niche Management (SNM) frameworks to AE in rural regions. This creates a blind spot, resulting in a disregard for the specific challenges and opportunities that rural regions bring. This gap overlooks the distinct dynamics influencing niche development (de Nijs, n.d.), (Klijnsma, 2018) and technological transitions in rural settings, such as low population density, dispersed infrastructure, and different heating systems. Scaling AE in a rural setting requires addressing challenges such as limited existing infrastructure for efficient distribution, financing and investment models that are not tailored to rural economic realities, and gaining social acceptance for new technology, all of which necessitate tailored strategies for these settings. This study seeks to fill the gap by focusing on rural regions with enormous surface water resources and identifying strategies and governance models to facilitate the development of collaborative and cooperative AE networks in rural communities.

1.2 Research Areas

In this study, we identify three types of aquathermal energy (AE) applications: (1) the collective model, (2) the cooperative model, and (3) the individual AE use model. However, due to the study's special objectives, we will largely focus on collective and cooperative models. The individual AE use model, in which only one household uses an AE system, is a feasible strategy, but for a number of reasons, this study has decided not to focus on it. According to (Hielscher et al., 2013), the scope of influence from individual systems is generally smaller than that of collective or cooperative models, particularly when it comes to community-wide energy transition and sustainability objectives. Personal energy independence can be achieved through individual systems, but they do not take advantage of the social advantages that are essential to our research goals, such as shared expenses, community involvement, and the possibility of larger-scale implementation. Second, the individual approach would not offer the same degree of economic efficiency or community participation in rural areas like Friesland, where shared resources and community cohesion are frequently crucial to overcoming obstacles related to infrastructure and the economy (Seyfang et al., 2013). This research aim to investigate how AE might be incorporated into larger community structures by concentrating on collective and cooperative models.

This research will explore two crucial areas to assess the impact of collective and cooperative aquathermal energy systems (AE) in rural settings. Collective and cooperative aquathermal energy (AE) systems offer distinct ownership and governance structures that can influence their impact in rural settings. Collective systems, typically owned and managed by a central entity, benefit from economies of scale and dedicated technical expertise, potentially making them more cost-effective to develop and operate in sparsely populated areas (Walker & Devine-Wright, 2008). Cooperative models, on the other hand, empower users through ownership and participation, fostering a sense of community responsibility and potentially leading to increased local acceptance, (Bauwens et al., 2016)

1. Impact on collective and cooperative AE systems

The study will look into how technological and institutional improvements can affect the development of collective and cooperative AE networks in rural areas. This entails assessing how technological improvements can assist overcome existing obstacles such as high upfront expenditures and insufficient infrastructure in rural areas. The study will look into the feasibility of deploying AE at a low cost using community ownership models, in which locals share the system's investment and benefits. The study's goal is to give policymakers, developers, and rural communities' valuable insights by examining the interaction between technology and institutions. This expertise can help them overcome current hurdles and realise the full potential of AE for developing a sustainable and effective heating solution in rural areas, and in particular the Friesland region.

2. Technological and institutional improvements

Firstly, it will explore recent advancements in individual heat pump technologies that utilize aquathermal energy. This includes examining innovative technologies like pre-insulated pipes that minimize heat loss during distribution, advanced control systems that optimize energy use based on demand, and the potential for integrating AE with renewable energy sources like solar or biomass. These advancements can significantly improve the efficiency and cost-effectiveness of rural AE networks, making them a more attractive proposition for both policymakers and rural communities.

In addition this research will look at how institutional frameworks are changing to support district heating projects. This analysis will focus on how policy instruments are being shaped to create a more enabling environment for rural AE adoption. One key area is regulatory frameworks and policies, where the research will examine how permitting processes are being modified to expedite project implementation, especially in rural areas. The study will look into how institutional collaboration programs among government agencies, academic institutions, and business entities may promote knowledge sharing and support for rural AE growth (Deals, 2019), (Sea, 2023).

1.3 The Problem Statement

Current research on aquathermal energy systems (AE) in rural areas ignores the obstacles and potential of scaling them using the Multi-Level Perspective (MLP) framework and Strategic Niche Management (SNM). This study focuses on Friesland to bridge the gap by examining how advances in surface water AE and emerging rural institutions can enable collaborative and cooperative AE networks.

1.4 The main research question

What factors influence surface water aquathermal energy (AE) niche development in rural Friesland region?

1.5 Sub-research questions

And four sub-questions to be researched as well:

1. What does the AE niche in Friesland look like?
2. How to analyse Friesland's existing heating system regime in the context of MLP framework?
3. How may SNM principles be applied to AE niche in Friesland and ultimately scaling AE?
4. What can we learn from other pilot and existing aquathermal energy projects in the world?

1.6 MOT perspective

From a Management of Technology (MOT) standpoint, this study on aquathermal energy (AE) in Friesland bridges the gap between technological innovation and societal impact. The MOT program focuses on understanding how emerging technologies might be managed for both commercial success and broader societal benefit (Delft, 2024). This research is completely consistent with that vision. By investigating AE's potential as a sustainable heating and cooling solution, the study directly addresses the critical societal issue of climate change (Falkner, 2016). Furthermore, it investigates the social and economic implications of AE adoption in Friesland, ensuring that the transition helps not just the environment but also promotes social equity and economic well-being in the region. This emphasis on the social sides of innovation demonstrates a thorough

awareness of the real-world complications that accompany technological achievements. In essence, the study does not simply analyse the technology, but also frames it as a possible generator of positive societal change, which is an important part of responsible innovation management examined in the MOT program (Delft, 2024).

The fundamental ideas of the Management of Technology (MOT) program are substantially supported by this research on aquathermal energy (AE) in Friesland; this is especially true of the courses MOT121A, MOT131A, MOT1442 and JIP.

The importance of leadership in technology-based organisations is emphasised in MOT121A (Leadership and Technology Management). Students who complete MOT121A will learn the management and leadership practices that can be applied to successfully navigate challenging technology environments. This study will apply this knowledge and investigate the role that leadership plays in the effective execution of AE projects in Friesland, taking organisational culture, decision-making procedures, and stakeholder management into account. Through the analysis of prominent figures' leadership approaches, the research will enhance comprehension of how proficient leadership may propel AE adoption and overcome obstacles.

A framework for examining innovation processes at various levels is taught by MOT131A (Emerging and Breakthrough Technologies). These ideas will be used in this study to look into how AE technology is spreading and being adopted in Friesland. Through determining the variables that impact the growth and distribution of AE, the research will advance knowledge of innovation trends in the energy industry. Additionally, the consideration of how AE can compete with or complement other renewable energy technologies will be informed by the course's emphasis on technological interactions.

MOT1442 (Social and Scientific Values) emphasizes the ethical and societal implications of technology. This is essential for considering the ethical and societal implications of AE, including its potential impacts on communities and the environment. Through incorporating MOT1442 into the discussion, this will emphasize the importance of ethical considerations and their role in responsible innovation management.

Through the integration of theoretical viewpoints and practical insights from the JIP project, this study provides a thorough framework for understanding AE in Friesland. In line with the larger objectives of the MOT program, this study will also assess the social, economic, and governance ramifications of AE technology.

1.7 Societal relevance

By exploring the potential of surface water AE to provide sustainable heating and cooling solutions, this research directly addresses the pressing issue of climate change and the need to transition away from fossil fuel dependence (Falkner, 2016). The success of this endeavour aligns perfectly with the goals outlined in international climate agreements (Falkner, 2016), contributing to a collective effort towards a more sustainable future. Furthermore, the research explores the social and economic implications of AE implementation in Friesland.

The AE's socio-technical system of surface water provides various benefits to Friesland. The infrastructure is mostly located underground and within water bodies, minimising its apparent influence on the landscape. Furthermore, the great efficiency of the heat pumps used in AE reduces the demand for wind turbines and solar panels when compared to other heating alternatives such as hydrogen or electric boilers. This reduces the total impact of the energy shift on Friesland's valuable landscapes (Fryslan, 2022). Alongside the environmental advantages, surface water AE promotes a collaborative approach that is well aligned with *Mienskip*, the Frisian concept of community. Collective heat networks can be formed inside towns or co-operatives to provide a sense of shared ownership and responsibility. This collaborative spirit can enable a socially equitable and faster energy transition for the region (Fryslan, 2022). The technology also opens up interesting potential for Frisian enterprises. Surface water AE, which range from the construction of heat networks and heat storage systems to the adaptation of dwellings and the provision of consulting and engineering services, can encourage regional economic growth and job creation. Furthermore, knowledge institutions in Friesland may play an important role in spreading knowledge about surface water AE and developing a trained workforce to support its growth (Fryslan, 2022). The success stories of Heeg, Oudehorne, and Leeuwarden demonstrate the potential of surface water AE in Friesland. Individual homes and

buildings have already been successfully heated using this approach, which is clearing the path for large-scale operations. Examples from Heeg, Sneek, Leeuwarden, Balk, and Terschelling demonstrate continuous efforts to heat entire neighbourhoods and villages with surface water AE (Deals, 2023), (Fryslân, 2022). Friesland can use *Wetterwaarmte* to unlock a sustainable future by encouraging collaboration, negotiating governance structures to address the unique problems of surface water sources, and developing public trust (Fryslân, 2022).

1.8 Research Outline

The research sub-questions in this master's thesis are addressed through a combination of methods, which are detailed in the document. The first sub-question, is answered through presenting an overview of the aquathermal energy (AE) systems in Friesland, drawing on insights from the literature, interviews, and case studies. The second sub-question, is addressed by using the Multi-Level Perspective (MLP) framework to examine the current heating system in Friesland, including the landscape, regime and niche levels, and by analysing the influence of external factors and the resistance to change from the current system. The third sub-question, is answered through the application of the Strategic Niche Management (SNM) framework to assess the current practices in Friesland, and explore the potential for scaling AE through knowledge exchange, network development, and policy advocacy. The fourth sub-question, is explored through the analysis of international AE projects, from which lessons in stakeholder engagement, legal frameworks, and financial support mechanisms are drawn. These sub-questions directly contribute to solving the main research question about the factors impacting AE niche development in Friesland. A detailed diagram of the research process is presented in Figure 3 below.

1.9 Reading Guide

This thesis follows a structured format : Chapter 1 introduces aquathermal energy systems, identifies literature gaps, and sets out the main research question with sub-questions. Chapter 2 explores the theoretical frameworks of Multi-Level Perspective (MLP) and Strategic Niche Management (SNM). The methodology, including case study selection, data processes, and ethical considerations, is detailed in Chapter 3. Chapter 4 shows the results by analysing the Friesland district heating regime, applying the SNM framework to assess aquathermal energy (AE) development, challenges, prospects, and nurturing strategies and addressing the sub-questions on AE in Fryslân. The thesis concludes in Chapter 5, where research questions are answered, limitations are discussed, and recommendations for future research and policy changes are provided. (Appendix A) include the Informed Consent Form, Data Management Plan, and Checklist for Human Research Ethics. (Appendix B) include the Semi-Structured Interview Questionnaire and Appendix C contains the preliminary stakeholder maps which served as the foundation for developing the final stakeholder map shown in Figure 10.

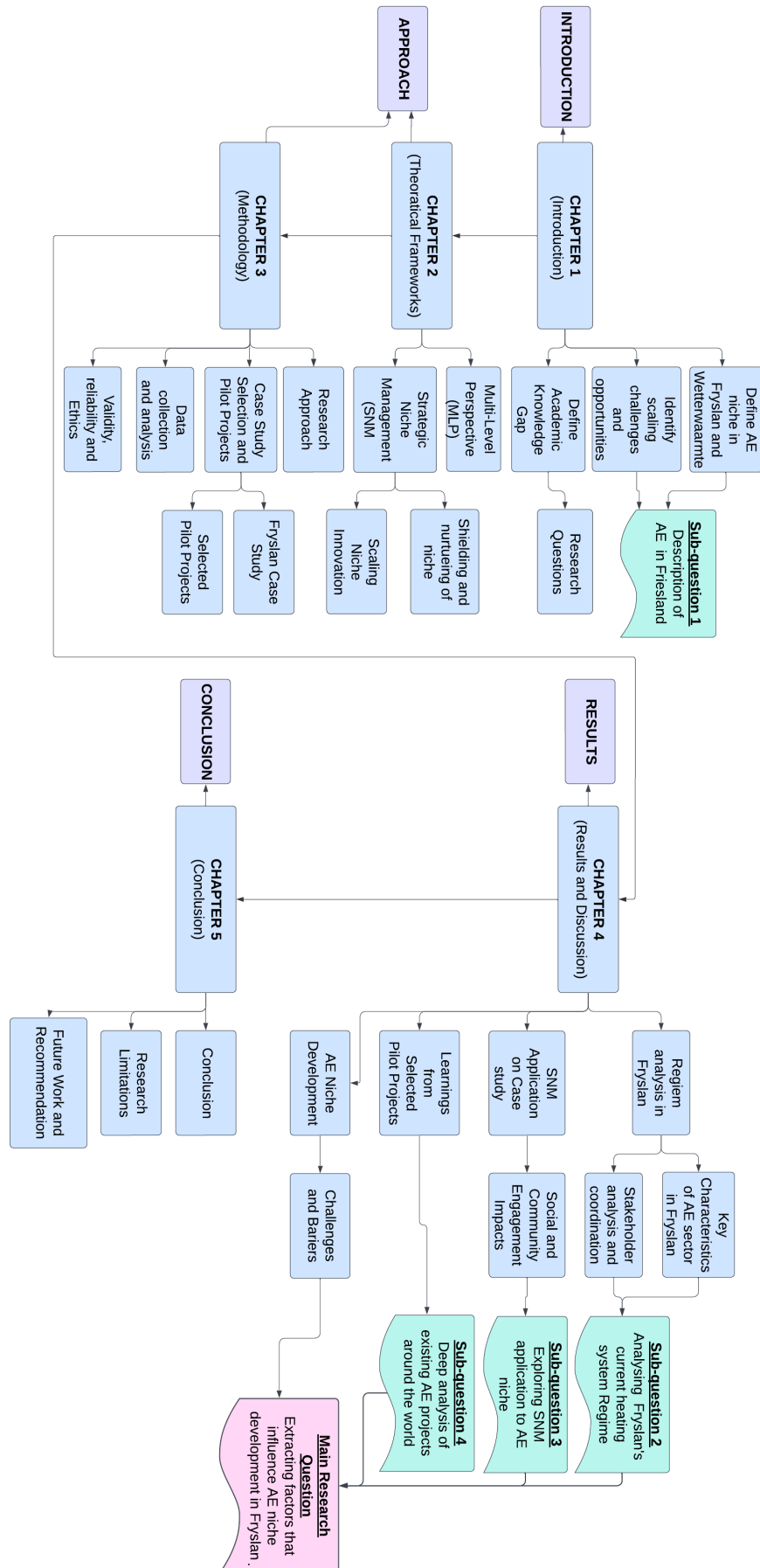


Figure 3: Thesis process diagram

2

THEORETICAL BACKGROUND

The upcoming section examines the theoretical frameworks that will be used in this research, focusing on the Multi-Level Perspective (MLP) and Strategic Niche Management (SNM). A detailed analysis of both frameworks will be presented, exploring their core concepts and their relevance to the research context.

2.1 Transition Studies Frameworks

Transition Studies is an interdisciplinary discipline that investigates how societies transition from one dominating socio-technical system to the next (Cherp et al., 2018). It focuses on understanding the dynamics of these transitions, the problems and possibilities they bring, and the tactics that can be used to encourage more sustainable transitions. The initiative towards sustainable heating solutions is a huge challenge, especially for rural areas that rely on traditional fossil fuel-based systems. Transition Studies, an interdisciplinary topic, provides helpful frameworks for analysing and fostering these changes (Cherp et al., 2018). They provide a conceptual lens through which researchers can interpret and explain the complex dynamics of socio-technical systems. This study will use two important Transition Studies tools: the Multi-Level Perspective (MLP) and Strategic Niche Management (SNM) as they provide useful tools for analysing and shaping transitions, especially those involving technological innovation and sustainability (Raven, 2005), (Hoppe et al., 2024), (Smith et al., 2005).

SNM and MLP frameworks offer a comprehensive lens to analyse the development and scaling of aquathermal energy niches from their perspective's. Their focus on niche development, their ability to handle multi-level analysis, and their compatibility with qualitative data make them well-suited tools for this research endeavour (Raven, 2005), (Hoppe et al., 2024), (Smith et al., 2005), (Kamp & Vanheule, 2015).

2.1.1 Multi-Level Perspective (MLP)

The Multi-Level Perspective (MLP) provides an effective lens for comprehending technology transformations. It sees change as a dynamic movement involving three interconnected levels. The landscape sets the broad stage, including social, economic, and environmental themes such as climate change and energy security. This landscape influences the overall setting of technological progress. Within this landscape, the regime level reflects the established order, which includes the dominant technologies, infrastructures, rules, and user practices that regulate a certain sector (Geels, 2002). Consider it the "status quo" within a field. Finally, niches arise as safe spaces for unique technology concepts and practices to grow and thrive. Operating outside of the mainstream regime, these niches provide an ideal environment for experimentation, learning, and innovation. Successful niches can pave the path for greater acceptance of these new technologies by proving their promise and overcoming initial obstacles. The MLP framework emphasizes the dynamic interplay between these levels. Landscape pressures can provide possibilities for niche innovations that unravel established regimes, while successful niches can eventually impact changes in the larger landscape (Geels, 2002), (Hoppe et al., 2024), (Smith et al., 2005).

1. Regimes

Regimes are the established socio-technical systems that control today's practices and technologies. Institutions, legislation, consumer preferences, and existing infrastructure can all act as impediments to change (Geels, 2002). (Geels, 2011) interprets the Multi-Level Perspective (MLP) as centred on the socio-technical regime. While the niche and landscape levels provide useful insights into innovation and the broader societal context, they only exist in respect to the current regime. The regime is the established system, which includes a network of participants (businesses and organisations), the official and informal rules that govern their behaviour (laws and conventions), and the physical infrastructure

and technologies.

Regime Dynamics in MLP include:

- **Regime Stability**

(Geels, 2002) defines regime stability as the resistance of the current system to change. This resistance could be manifested in economic, technological, and cultural norms that favour traditional energy, providing hurdles to its integration.

- **Regime Resistance**

(Geels, 2002), points out that, in addition to stability, the regime may actively block change by pushing against new technology or policies that benefit the niche, thereby maintaining the status quo.

- **Regime Reconfiguration**

According to (Geels, 2002), regime reconfiguration occurs when portions of the regime adapt in response to niche demands or landscape changes. This could imply that existing energy systems be modified to integrate or complement niche technologies.

(Geels, 2005) explains the variables that contribute to the regime's stability. He outlines three important mechanisms that function as anchors, opposing change:

- Actor Networks and Vested Interests:** As a result of established ties and cultural norms, regime players, such as businesses and organisations, become strongly involved in the existing system. This produces considerable resistance to any meaningful change, making it impossible to deviate from the current path (Geels, 2005).
- Institutional Frameworks:** Institutions, which include both formal regulations (laws) and informal structures like conventions, values, and expectations, reinforce the regime. These institutions function as unseen laws, controlling actors' behaviour and limiting their ability to imagine alternative pathways outside the current system (Geels, 2005).
- Material Lock-In:** Existing infrastructure and technology require significant investments. These systems' extensive inter-dependencies generate enormous inertia, making them resistant to change. These deeply established habits and technology become so integrated into society that it is impossible to fathom a world without them (Geels, 2004), (Loorbach & Verbong, 2012).

Because of these obstacles, new ideas (niches) frequently struggle to gain traction within the dominant system. However, if the system weakens, it may create an opportunity for change. This transformation could include new technologies, behaviours, policies, and infrastructure, eventually leading to a new dominant system (Geels, 2002).

2. Landscapes

The landscape refers to the larger societal background, which includes cultural trends, political ideologies, and environmental forces. This context determines the overall direction of technological evolution, which is influenced by changes at the niche and regime levels. In contrast to the dynamic forces operating within niches and regimes, the landscape functions as an external, nearly unchanging force that shapes the fundamental substrate of these dynamic systems. (Van Driel & Schot, 2005)) categorize the landscape's diverse factors into three distinct types:

- Slow-changing or static factors:** involves components such as climate change, which occur over long time frames (Van Driel & Schot, 2005).
- Long-term transformations:** For example how the development of the internet has changed communication and the exchange of information (Van Driel & Schot, 2005).
- Rapid external disruptions:** Unpredicted occurrences such as pandemics or financial crises can serve as potent inducers of transformation (Van Driel & Schot, 2005).

Landscape has an unquestionable influence on forming activities and regimes, frequently serving as a slow force for technological advancement over decades. However, the landscape isn't completely stagnant. Sudden changes at this level can dramatically affect the environment, potentially destabilising the existing regime. This disruption has the potential to open up possibilities for niche innovations to develop and challenge established norms (Geels & Schot, 2007).

Landscape Dynamics in MLP include:

- Landscape Influence

(Geels, 2002) defines landscape influences as external pressures on both niches and regimes. Climate policies, public demand for sustainability, and global energy patterns all create chances for niche to thrive.

- Cultural shifts

According to (Geels, 2002), cultural transformations like as increased environmental consciousness can influence the landscape, forcing the regime to adjust or establishing a niche by altering social values.

- Technological Trends

(Geels, 2002) mentions that global technology trends, such as the quest for renewable energy, might change the landscape. This means capitalizing on trends that favour sustainable technologies, thereby increasing its integration potential.

3. Niches

Niches are secure environments in which new technologies and behaviours arise and develop. They provide a conducive setting for experimentation and refining, allowing innovations to grow before confronting the problems of the dominant system. The niche level serves as a testing ground for innovation (Geels, 2002). These innovations are the result of careful consideration of the state of the industry, utilising skills and expertise specifically designed to meet its demands.

Niche Dynamics in MLP include:

- Regime Interaction

(Smith et al., 2010) define regime interaction as when niche inventions interact with the established energy regime. A niche may challenge the regime by exhibiting greater efficiency or by integrating into current frameworks, affecting transitions via this dynamic connection.

- Niche Protection

(Smith et al., 2010) define niche protection as fostering conditions that allow a niche to flourish without immediate commercial constraints. This could include subsidies or regulatory exemptions that allow it to expand until it becomes competitive.

- Niche Advocacy

(Smith et al., 2010) highlight how advocacy activities can influence public and policy support. This includes initiatives that promote the benefits of the niche and influence niche-regime interaction by creating a favourable climate for adoption.

According to (Geels, 2011), social networks are established, collaborative learning processes occur, and these activities are guided by common expectations. They do, however, also have to contend with inherent uncertainties, which can range from the innovation's technical design to the dynamics within the niche network and the preference preferences of potential customers (Geels, 2004).

One significant benefit is that niches frequently serve as secure environments. This gives emerging technologies and practices the room and time to develop in relative isolation from the intense competition of mainstream markets.

There are three main circumstances in which niches may gain momentum:

- (a) **Clear expectations and a shared understanding:** When all parties are aware of the potential and goal of the invention (Geels, 2011).
- (b) **Stable configuration, also known as "dominant design":** When the innovation's functional aspects are well-defined as a result of the niche's learning processes (Geels, 2011).
- (c) **Support from significant players:** When significant players see the promise of a niche innovation and offer resources and legitimacy to help it flourish (Geels, 2011).

Niche ideas face considerable obstacles when trying to establish traction under a strong and stable system, but there may be a crucial window of opportunity if the regime is weakened by the landscape. But in order for niche innovations to take advantage of this chance, they need to be fully developed and equipped to deal with the ever-changing landscape (Geels & Schot, 2007). All the above can be demonstrated in Figure 4

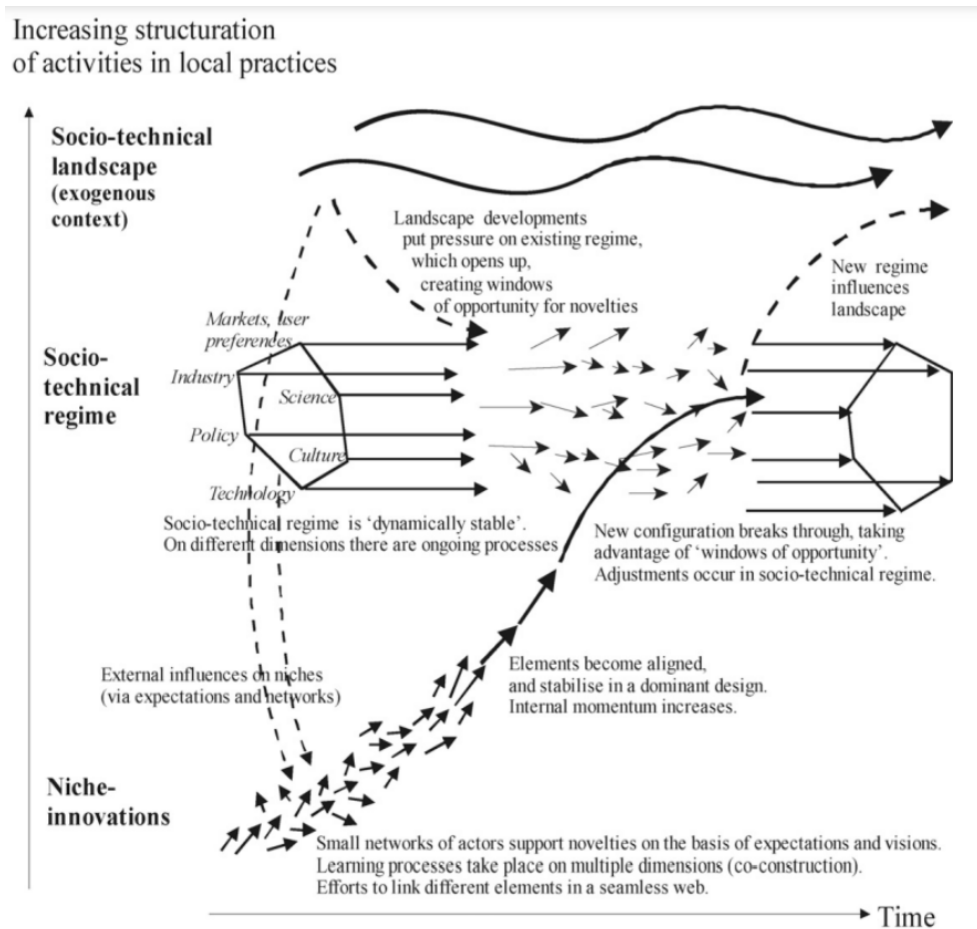


Figure 4: Multi-level perspective on transitions (Geels & Schot, 2007).

The MLP essentially indicates the fact that internal learning, enhanced performance, and the endorsement of powerful organisations are the main ways in which niche innovations gain traction. The regime is under pressure from landscape-level changes, and destabilisation of the regime opens the door for well-developed niche innovations to emerge and possibly change the current regime (Geels & Schot, 2007).

2.1.2 Strategic Niche Management (SNM)

Strategic Niche Management (SNM) extends the MLP framework by providing a prescriptive strategy for actively managing the establishment and scaling of new technologies within niches. It offers a set of tools and tactics aimed at three critical internal processes. The first is about "voicing and shaping expectations." This entails establishing platforms for knowledge exchange and collaboration among researchers, policy-makers, businesses, and prospective consumers of new technology (Raven, 2005), (Hoppe et al., 2024). By encouraging debate and defining a shared vision, SNM helps to build momentum and shape expectations for technology development. Second, SNM focuses on "network formation." This entails establishing strong networks among varied participants within a niche. Workshops and talks can bring together researchers, corporations, policymakers, and prospective users to promote collaboration and knowledge sharing. These networks have the potential to speed innovation while also overcoming technological and social acceptance constraints. Finally, SNM encourages ongoing learning via "learning processes." Pilot projects are critical instruments for implementing and monitoring small-scale projects to collect useful data and guide future development, ultimately optimising the technology for real-world applications. User involvement promotes social learning by gathering and responding to comments to improve technology and enhance social acceptance. By implementing these internal processes, SNM tends to foster a healthy ecosystem in which promising new technologies can thrive within niches, eventually aiding their move to the mainstream (Raven, 2005), (Hoppe et al., 2024).

This paradigm emphasises three main internal processes:

1. Voicing and Shaping Expectations

The development of knowledge exchange platforms for researchers, policymakers, management agencies, and the general public. SNM fosters collaboration through seminars and debates, allowing stakeholders to express and shape their aspirations. This enables stakeholders to establish the technology's vision and goals together, drawing resources and instilling a sense of ownership (Raven, 2005), (Hoppe et al., 2024).

Voicing and Shaping Expectations dynamics in SNM include:

- Nice Empowerment

According to (Kemp et al., 1998), niche empowerment entails creating a favourable climate for niche innovations by aligning the expectations of multiple actors. This includes not only technical demonstrations, but also developing a narrative around the technology to generate confidence and legitimacy. For example, public engagement efforts such as community seminars or open communication can boost stakeholders' trust in the technology, which is critical for the speciality to gain traction. The process of empowering is linked to setting realistic yet visionary expectations, encouraging stakeholders to imagine a future in which the technology plays an important part.

- Institutional Embedding

(Schot & Geels, 2013) explore how incorporating specialized ideas into existing institutional frameworks requires adjusting expectations. This entails influencing policies to encourage technology adoption by aligning institutional expectations with the niche's aims, hence facilitating the technology integration into the mainstream socio-technical system.

- Vision Building

(Schot & Geels, 2013) define vision building as the creation and promotion of a shared vision for the technology's future position in society. This entails creating narratives around which stakeholders may rally, imagining a sustainable future in which the technology is central, and thereby driving the technology's development and acceptance.

- Legitimation

(Kemp et al., 1998), emphasize the necessity of legitimation, in which a specialized technology acquires acceptance by harmonizing with society ideals. This could entail showing the technol-

ogy's environmental benefits or economic feasibility in order to gain public and regulatory support by meeting social standards for sustainability.

The analysis combines both external and internal expectations. It examines the clarity, confidence, and quality of actors both inside and beyond the niche (Kamp & Vanheule, 2015)). In addition it looks into how these expectations are affected by larger landscape elements, regime dynamics, and even the possible formation of competing niches (Kamp & Vanheule, 2015).

2. Network Formation

This aspect highlights the development of strong networks among varied actors. This can include workshops and talks with scholars, policymakers, businesses, and rural communities. These networks can speed innovation by encouraging cooperation and knowledge exchange, as well as remove technological or social acceptance barriers (Raven, 2005), (Hoppe et al., 2024).

Network Formation dynamics in SNM include:

- Networks/Alliances

(Kemp et al., 1998), argue that networks and alliances are essential for speciality development. This entails forming partnerships among multiple stakeholders such as public institutions, corporate sectors, and communities to facilitate resource sharing and collective action to progress the projects.

- Brokerage

According to (Kemp et al., 1998), brokerage refers to the role of intermediaries in facilitating connections and promoting network building. In the technology's environment, brokers may assist in matching the interests of various stakeholders, ensuring efficient collaboration in the technology's activities.

- Stakeholder Mapping

(Schot & Geels, 2013) state that mapping stakeholders is critical to understanding their roles and contributions. This entails identifying all key stakeholders, ranging from local governments to technology providers, and establishing a comprehensive network to support the technology's growth.

This section assesses the quality of interactions between various actor groups within sub-networks, as well as the desired network composition and completeness. (Kamp & Vanheule, 2015). It evaluates the effectiveness of these groups' contributions to niche development. Furthermore, it analyses the extent to which the actors' tactics, aspirations, and visions align with the overall trajectory of niche development (Kamp & Vanheule, 2015).

This section examines the key factors influencing the technology's wider adoption. It analyses the improvements needed in associated technologies, infrastructure, and design criteria for broader use (Kamp & Vanheule, 2015). It also investigates the creation of production and maintenance networks to facilitate wider distribution. Additionally, it evaluates how stakeholders are informed about the technology's environmental and social impact through social and environmental learning (Kamp & Vanheule, 2015), including understanding user needs and cultural relevance within the niche. Finally, the analysis explores the evolving landscape of rules, regulations, and incentive programs and analyses how their evolution can affect adoption (Kamp & Vanheule, 2015)).

3. Learning Processes

The ongoing learning through experimentation and user interaction. Pilot programs are key tools in this process. By implementing and monitoring small-scale projects, useful data can be gathered to inform future development and optimise the technology for real-world applications. Additionally, user interaction promotes social learning by addressing public concerns and gathering feedback to improve the technology and increase social acceptance (Raven, 2005), (Hoppe et al., 2024).

Learning Processes dynamics in SNM include:

- Niche Innovation

(Schot & Geels, 2013) define niche innovation as the creation of new technologies or processes in protected areas. Innovations are refined by learning from experimental projects, responding to feedback, and enhancing technology to challenge or supplement established methods.

- Niche Nurturing

(Schot & Geels, 2013) define nurturing as protective measures that enable for learning. Financial support, regulatory sandboxes, and learning from both local and global experiences are all part of the strategy to improve technological maturity and acceptance.

- Learning Processes

According to (Schot & Geels, 2013) , these are the methods by which niche players learn, adapt, and improve. This could include knowledge-sharing workshops, adjusting plans based on stakeholder feedback, or implementing international best practices.

- Experimentation

(Schot & Geels, 2013) emphasize experimentation as a method of learning in which innovations are evaluated in real-world settings. This hands-on approach promotes practical learning by changing the systems based on real performance and user interaction.

- Second-Order Learning

(Schot & Geels, 2013) define second-order learning as learning about the learning process. This could entail improving stakeholder engagement approaches or fine-tuning how pilot project learnings are used to larger deployments.

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Niche process	Indicator	What is analysed
Expectations	Internal expectations	The quality, robustness and specification of expectations of the current actors in the niche
	External expectations	The awareness and confidence level of actors outside the niche
	Exogenous expectations	Exogenous expectations originating from developments that are external to the niche expectations: landscape and regime factors, the development and/or rise of other niches
	Endogenous expectations	Expectations originating from learning experiences and network composition within the niche
Network formation	Network composition	Desired network composition and its completeness
	Quality of the sub-networks	How far do actor groups contribute to niche development
	Network interactions	How network actors are interacting
	Network alignment	How actor's visions, expectations and strategies are in line with the niche development
Learning processes	Technical development and infrastructure	Learning about design specifications, complementary technology and the required infrastructure needed for technology dissemination
	Industrial development	Learning about the production and maintenance as well as the network needed to broaden technology dissemination
	Social and environmental impact	Learning about the technology's impact on safety, energy and the environment
	Development of the user context	Learning about the end-user characteristics, their requirements, their barriers for technology adoption and the meanings they attach to a new technology
	Government policy and regulatory framework	Learning about the institutional structures and legislation that are relevant for dissemination, and the incentives they can provide to encourage adoption
	Innovation potential and analysis	Learning about the available resources to enhance the innovation
	Appropriate business models	Learning about business models that enable successful market penetration

Figure 5: The three niche processes and their indicators table (Kamp & Vanheule, 2015), (Hoppe et al., 2024).

2.1.3 Frameworks' Limitations

As mentioned above both the Multi-Level Perspective (MLP) and Strategic Niche Management (SNM) can offer valuable insight for understanding socio-technical transitions. However, it's important to acknowledge their limitations, especially in the context of this research on "Wetterwaarmte" adoption in Friesland.

1. Multi-Level Perspective (MLP)

The MLP can occasionally give a linear and deterministic perspective of transitions, meaning that niche innovations ultimately lead to regime shift. This disregards the complicated interplay of elements and the possibility of path dependency. Furthermore, MLP concentrates on broader societal trends and institutions, possibly overlooking the agency and specific acts of individual actors inside niches (Smith et al., 2010), (Lachman, 2013).

2. Strategic Niche Management (SNM)

SNM focuses on possible opportunities for successful niche growth while downplaying the major hurdles and resistance that may arise from the current system and geography. Furthermore, SNM concentrates primarily on the niche level, potentially ignoring the larger context and the impact of external forces beyond the niche's control (Smith et al., 2010), (Lachman, 2013).

Another important aspect that may occur is that case studies do not always correspond exactly with theoretical frameworks. This does not inherently invalidate the study or the frameworks. Instead, it may provide an opportunity to: (Zolfagharian, 2019)

1. **Highlight the limitations of the frameworks:** Discuss how the unique aspects of the case study highlight constrains or blind spots in MLP and SNM. This can provide significant information on the

frameworks' applicability and potential areas for future development.

2. **Adapt the frameworks:** Through adapting or changing the frameworks to better suit the case study. This could include focusing on specific components of the frameworks that are more relevant, or mixing elements from both MLP and SNM in a way that better expresses the case's complexity.
3. **Create new insights:** Differences between the framework and the case study can lead to the development of new insights or theoretical propositions. By analysing the misalignment's, new features or dynamics in the case study may be discovered that require further explanation or question existing framework assumptions.

Finally, the idea is to use the frameworks as tools to obtain a better knowledge of the case study, even if they aren't a perfect fit. By recognising the limitations and adjusting or extending the frameworks as needed, the research can still get significant insights and contribute to the development of these theoretical tools (Zolfagharian, 2019).

2.1.4 MLP and SNM Integration

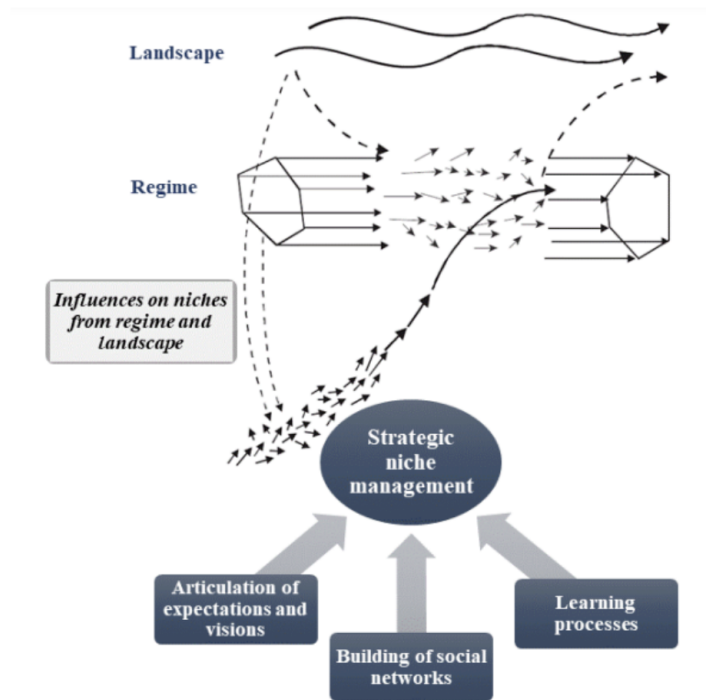


Figure 6: MLP and SNM Integration (Hoppe et al., 2024).

By offering an organised flow for comprehending and promoting sustainable innovations, the Multi-Level Perspective (MLP) enhances Strategic Niche Management (SNM). The identification of landscape dynamics, such as environmental trends and economic movements, is initially guided by MLP. This helps with stakeholder mapping, identifying weak points and areas for improvement in the current systems, and evaluating the stability of the regime. In this setting, SNM maps stakeholder networks, examines sentiments, and monitors progress in order to foster niche ideas. Stakeholder activities are aligned through the use of qualitative content analysis to articulate clear visions and expectations, while social network analysis creates strong collaborative networks. Lastly, SNM enables ongoing learning from pilot initiatives, ensuring that, with the help of insights from MLP's more comprehensive contextual analysis, niche innovations can effectively evolve and pose a threat to established regimes (Hoppe et al., 2024).

3

METHODOLOGY

To research the opportunities and challenges associated with governing and scaling AE in Friesland, a qualitative research design is used as there is currently no knowledge available particularly for both governance and scaling when it comes to AE in rural regions using the Multi-Level Perspective (MLP) and Strategic Niche Management (SNM) frameworks. Qualitative analysis concentrates on interview content, deriving complex insights into community dynamics, stakeholder viewpoints, and qualitative elements impacting social and economic resilience. A variety of techniques are utilised to gather the data. Analysis of the literature and documents is done at every step of the research process. Reports, scholarly publications, and websites were among the sources used to gather data for this research. This analysis is first performed to get a broad overview of the current state of affairs about AE in Friesland. The results of the empirical and analytical aspects of the research are further supported later on in the process by the literature, document analysis and semi-structured interviews with the key actors in the Friesland region's AE industry.

3.1 Research Approach

In this research, a case study approach is used in order to gain a comprehensive understanding of the issue through a detailed analysis. A case study is an empirical investigation that looks at a current phenomena in the context of real life, particularly in situations where it's difficult to distinguish between the two. It uses a variety of evidence (data) sources to respond to "how" and "why" questions (Yin, 2009), which aligns with this research objective.

Additionally, a thorough literature research will be carried out to lay the groundwork for understanding the social and institutional dimensions of AE development in the selected case study. To answer the first sub-question, relevant scholarly articles, reports, and policy documents about stakeholder communities and niche AE systems in the selected case study will be investigated. By rigorously evaluating these resources, the study will provide a precise description of the current situation of niche AE in the selected case study.

Semi-structured interviews with experts and stakeholders can identify significant stakeholders in the process, including their roles, viewpoints, and influences. Semi-structured interviews with responsible sectors are necessary to explore the existing potential and challenges of AE in selected pilots, followed by qualitative analysis. This research method can assist identify the most pressing difficulties and the techniques employed to overcome them.

To identify the main niche characteristics of AE in selected case studies, including learning processes, network formation, and expectation dynamics, an extensive Strategic Niche Management (SNM) analysis will be conducted using the gathered data from previous sub-questions. The SNM application will provide insights and methods for developing AE in the selected case study.

Finally, an in-depth analysis of successful AE projects in other areas with similar geological characteristics can be investigated through literature review. This will provide valuable insights into approaches transferable to the specific context of the main case study. This will enable a thorough analysis of the governance frameworks, financing methods, and community engagement strategies used in those initiatives, thereby providing significant lessons learned and transferable information to the selected case study region.

3.2 Case Study Selection

Friesland, a rural province in the northern Netherlands, has an area of 3,336 km² and a population of 661,956. The province's capital, Leeuwarden, is located in the north-central region and has a population of almost 100,000 people. In Figure 7 and Figure 8 presented the map of Netherlands and Friesland's major cities and provinces respectively. The province extends inland from the IJsselmeer and the North Sea (west and

north), and it contains four of the West Frisian Islands off the northern shore. Friesland is drained by an extensive network of canals, streams, and lakes, especially in the north and west. The province's elevation rarely reaches 50 feet (15 metres) above sea level. Friesland has the lowest population density of any province is only a fraction of the national average (Britannica, 2024), (Europe, 2024).



Figure 7: Netherlands's map, (Britannica, 2024).

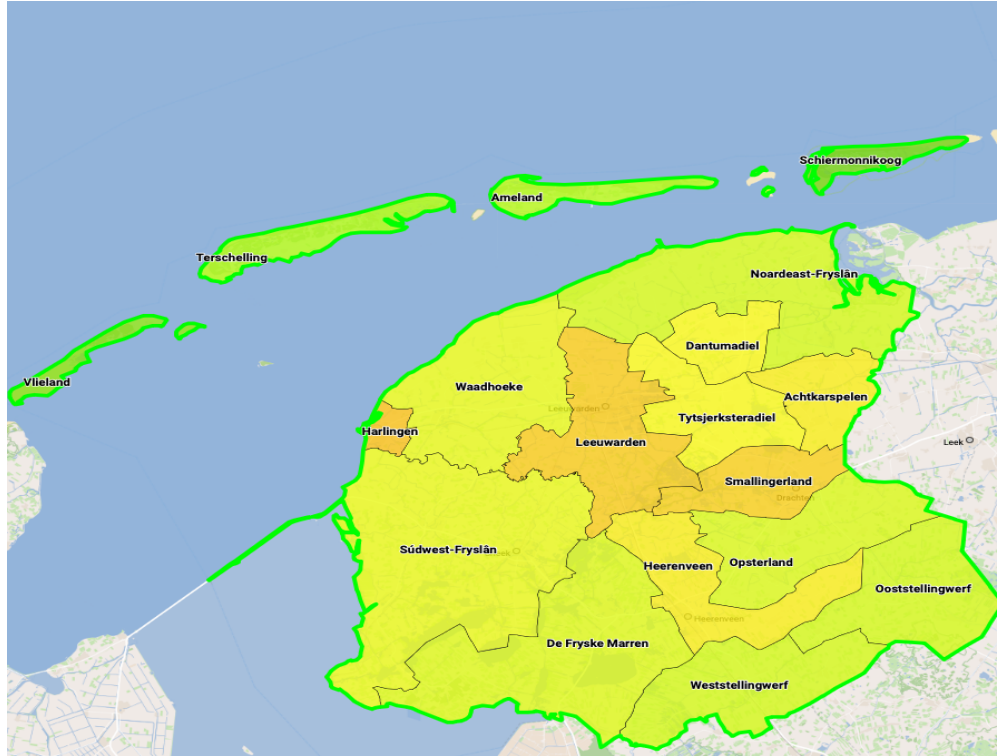


Figure 8: Friesland's Map, (Europe, 2024).

This study focuses on Friesland region, a rural region with enormous surface water resources that is currently aiming to have large-scale AE projects. Following the successful completion of many AE projects in Friesland that served to heat a whole building, larger AE projects are now being designed to heat entire Friesland's neighbourhoods or villages (Fryslan, 2022). Examples of larger projects can be seen at Heeg, Sneek, Leeuwarden, Balk, and Terschelling (Fryslan, 2022). For example The Heeg case (warmheeg) is a community-driven project. The AE system in Heeg is organized as a collective energy cooperative with the goal of using surface water from the Hegermeer to heat the village in an environmentally responsible manner. Heeg is currently carrying out excavation work for its AE project, which is an important phase in the system's deployment. The excavation consists of digging to install the AE system's infrastructure, such as heat exchangers and piping that will connect the surface water source to the heating network. This infrastructure is crucial for extracting thermal energy from the water and then distributing it to homes and structures in the the village (Warmheeg, 2024).

The specific projects within the Wetterwaarmte niche, such as those in Heeg, Oudehorne, and Leeuwarden (Sea, 2023), (Deals, 2023), will be examined to better understand the governance frameworks, funding models, and social acceptability techniques used for successful surface water AE implementation in Friesland. Applying MLP and SNM frameworks for the case studies and pilot projects can help identify effective models for managing and coordinating AE development and community engagement strategies, best practices for involving and gaining acceptance from local communities (Hoppe et al., 2024), (van de Witte, 2023).

3.2.1 Pilot Case Studies

Apart from comprehensive case studies of AE projects in Friesland, looking at projects in other regions with comparable geological features might also provide significant insights. Literature reviews can be a valuable resource for identifying these case studies for example those that concentrate on projects in rural Sweden, Belgium, and Denmark. For instance projects from the the Interreg North Sea II WaterWarmth project (WaterWarmth, 2022), such as the Buda Island initiative in Belgium and Middelfart in Denmark. By examining these case studies and analysing achievements and difficulties encountered by other societies applying AE, we may then optimise our strategy and possibly prevent mistakes in Friesland's initiatives.

3.3 Data collection

1. Desk study

A thorough assessment of current academic literature, government reports, and industry publications will be done to obtain information on AE technology, governance frameworks, and scaling techniques in similar countries. This will establish a solid foundation for the research and reveal potential best practices. The theoretical framework described in Chapter 2 and the literature background provided in Chapter 1 are the outcomes of an extensive examination of the academic literature. This framework offers a perspective through which empirical data is evaluated.

2. Stakeholder Interviews

Based on the stakeholder analysis which will be presented in the next chapter, semi-structured interviews will be performed with important stakeholders from various sectors. An overview of the 14 main research participants, including their positions, organisations, and areas of expertise, is given in the interview Table 1. The interview questions Appendix B are based on the theoretical frameworks of SNM and Multi-Level Perspective (MLP), demonstrating a deductive approach, in order to help guide and categorize the answers. The contributors are divided among external specialists from Denmark, Belgium, and Sweden as well as local Friesland stakeholders in this table. These participants offer a variety of viewpoints on aquathermal energy systems, from senior advisers at consulting firms to project managers at municipalities. Their observations serve as the basis for examining the evolution of AE niches, exposing both local difficulties and lessons that are relevant worldwide. All interviews are conducted and transcribed in English. Microsoft Teams software was used for all interviews, recorded with consent, and generated transcripts through the software, were then edited for accuracy. 14 interviews were conducted for this study, each assigned a three-letter acronym listed in Table 1. 13 interviews were conducted by the researcher of this study however, one interview's transcript was acquired after getting the consent of the interviewer and the interviewee. 24 potential interviewees were contacted, of which two are not active in the field any more, three declined and five did not respond.

No.	Role	Organization	Scope	Acronym
1	Heat transition	Mun. of De Fryske Marren	Friesland	MFM
2	Co-founder of Consultant company	Consultant Private company	Friesland	CC1
3	Senior advisor sustainability and Environmental issues	Municipality Leeuwarden	Friesland	MOL
4	Project Leader, Eigen warmte Balk	Energy cooperation	Friesland	PLB
5	Project coordinator of Water-Warmth	Province of Friesland	Friesland	PF1
6	Project manager for aquathermal and collective heating systems	Province of Friesland	Friesland	PF2
7	Senior advisor at Consultancy company	Consultant Private company	Friesland	CC2
8	Consultancy company	Consultancy and engineering Private company	Friesland	CC3
9	Council member in De Poask	Energy cooperation	Friesland	PLD
10	Energy Transition Advisor wetterskip	Water board	Friesland	WWB
11	Project Leader of Heeg	Energy Cooperation	Friesland	PLH
12	Head of Climate	Middlefart municipality, Denmark	External	MMD
13	Subsidie-adviseur	Municipality of Kortrijk, Belgium	External	MKB
14	Senior lecturer in Sustainability science in Lund University, Sweden	University	External	SSL

Table 1: List of Interviews

3.4 Data analysis

(a) Stakeholder Analysis

Stakeholder analysis is a critical tool for identifying and comprehending the individuals or groups who can influence or be impacted by a specific project or technology (Bryson, 2004), in order to explore how they may influence the Wetterwaarmte project in Friesland, the research can proactively address potential challenges, build strong relationships, and optimize the project's outcomes.

Through a stakeholder analysis, the following can be addressed:

- Identify the important players: Determine whether persons or groups have substantial influence or a vested interest in the success of aquathermal energy adoption (Bryson, 2004).
- Create targeted strategies: Tailor communication and engagement strategies to different stakeholder groups based on their power and interest levels (Bryson, 2004). A clear understanding of stakeholder needs and expectations facilitates effective communication. By tailoring messages and engagement strategies to different stakeholder groups, the research can increase the likelihood of successful communication and collaboration.
- Risk Mitigation: Identifying potential conflicts or resistance early in the project allows for proac-

tive measures to be implemented. By understanding the concerns of key stakeholders, the research can develop strategies to address them and minimize the risk of project delays or disruptions (Bryson, 2004).

Based on the stakeholder analysis which will be presented in the next chapter, semi-structured interviews will be performed with important stakeholders from various sectors. An overview of the 14 main research participants, including their positions, organisations, and areas of expertise, is given in the interview Table 1. The interview questions Appendix A are based on the theoretical frameworks of SNM and Multi-Level Perspective (MLP), demonstrating a deductive approach, in order to help guide and categorize the answers. The contributors are divided among external specialists from Denmark, Belgium, and Sweden as well as local Friesland stakeholders in this table. These participants offer a variety of viewpoints on aquathermal energy systems, from senior advisers at consulting firms to project managers at municipalities. Their observations serve as the basis for examining the evolution of AE niches, exposing both local difficulties and lessons that are relevant worldwide.

3. Thematic Analysis

Qualitative data from 14 interviews and case studies were analysed thematically to uncover recurring patterns, problems, and opportunities for AE governance and scalability in Friesland. This analysis identifies major trends emerging from the data (Jason & Glenwick, 2016), allowing for a more in-depth understanding of the social, economic, and institutional reasons impacting the progression of surface water AE in the region. This section describes how the insightful information acquired from the expert interviews will be examined. The question set is categorized into 6 sections: Introductory, Technical and Operational Aspects, Governance and Policy, Economic and Environmental Aspects, Future Outlook and Challenges and ends with Closing questions, Figure 31 Figure 30. A text record of every discussion was produced by transcribing the taped interviews. These transcripts were then condensed using the interview questions that were categorised in order to guarantee concentration and clarity. The important themes and patterns that emerge from the data will then be extracted through analysis of these summaries. (ATLAS.Ti) is the software that was used for the qualitative analysis. Applying codes to the summary is made straightforward by the software. The codes will be applied according to each interview. The primary deductive and inductive codes produced by thematic analysis of the qualitative data are listed in the code Table 2 and Table 3. A systematic lens for examining the evolution of aquathermal energy (AE) is provided by deductive codes, which are taken from pre-existing theories and frameworks and highlight established themes such stakeholder collaboration, scaling strategies, and economic barriers. Inductive codes, which are derived directly from the data, guarantee that the analysis is based on participant experiences by capturing context-specific insights such as building trust, cold weather performance, and regional adaptations

4. **MLP and SNM Frameworks Analysis** The data is analysed and the research objectives are addressed using the MLP and SNM frameworks. When examining niche innovations, the Multi-Level Perspective (MLP) and Strategic Niche Management (SNM) frameworks are commonly combined (Van Eijck & Romijn, 2009), (Kamp & Vanheule, 2015), (Geels & Schot, 2007). As indicated by (Kamp & Vanheule, 2015), MLP provides a broader perspective by accounting for external influences that may influence niche growth. In a similar vein, (Van Eijck & Romijn, 2009) stress that a comprehensive knowledge of these multi-level influences is crucial. As a result, this thesis uses MLP to support its SNM-based analysis. We can find potential obstacles and opportunities for AE niche innovation by using MLP. The MLP framework will be utilised to map the diverse elements influencing the niche and offer a comprehensive assessment of these influences. Furthermore, investigation will be carried out further using the SNM framework. In order to investigate how stakeholders are currently using knowledge exchange, network development, and policy advocacy to encourage greater adoption of surface water AE. This analysis offers recommendations for how these techniques might be improved to help the niche grow and transition into the mainstream.

5. Explanation of the coding process

Since expectations play a crucial role in determining stakeholder engagement and niche development, they were considered an analytical emphasis in this study, as stressed by Strategic Niche Management

(SNM). The emphasis on expectations explores how stakeholder visions, goals, and confidence change over time and interact with actual project outcomes, (Kamp & Vanheule, 2015). In order to extract codes from 14 interviews, an abductive coding strategy that combined deductive and inductive methods was utilized. As it provides a compromise between the openness of simply inductive methods, which may lack theoretical foundation, and the rigidity of completely deductive approaches, which may overlook new insights (Timmermans & Tavory, 2012). Initially, the interview questions Appendix A were based on the theoretical frameworks of SNM and Multi-Level Perspective (MLP), demonstrating a deductive approach. For example, questions like 'Who are the key stakeholders involved in aquathermal energy projects in Fryslan?' and 'What role do government policies and regulations play in promoting or hindering the development of aquathermal energy in Fryslan?', examined how policy and stakeholder collaboration affect niche development, directly addressing theoretical expectations. "Do you have any additional insights or perspectives on the future of aquathermal energy in Fryslan?" and "Are there any under-represented or overlooked stakeholders that should be involved?" are two examples of the more general, open-ended questions that were included in the interviews in order to incorporate inductive elements. These questions made it possible for novel subjects about changing expectations to surface, offering special perspectives on stakeholder dynamics and public engagement. According to (Strauss & Corbin, 1998), this procedure demonstrates how abductive coding allows us to improve comprehension by combining theoretical expectations with empirical facts, resulting in a more comprehensive analysis.

(SNM) and (MLP) frameworks were used to analyse data pertaining to aquathermal energy transition in order to develop the deductive codes Table 2. The relevance to the frameworks is derived from the frameworks' dynamics of each of the SNM's and MLP's element of the as presented in Chapter 2, such as the landscape influence, Regime stability and Regime interaction. To represent niche development, SNM identified "Scaling Strategies" codes such as "Regional knowledge exchange," "Pilot projects," and "Adapting global lessons." These codes focus on learning processes within niches to improve the implementation of AE, test innovations in protected spaces, and customize global insights for local relevance.

SNM's emphasis on setting expectations and visions for niche empowerment by engaging communities, raising awareness, promoting trust through clear communication, and showcasing AE's feasibility, as well as MLP's landscape influence by changing public perception and indirectly pressuring the regime, were the sources of the "Public Engagement" codes, which include "Community workshops," "Education campaigns," "Transparent communication," and "Real-world demonstrations." Examples of these include comments such as "Workshops and public awareness programs inform communities about AE benefits" (MKB, Interview 13, 2024). "Stakeholder Collaboration" codes like "Cross-sector partnerships," "Early engagement," and "Multistakeholder involvement" originated from SNM's emphasis on forming alliances and networks, demonstrating the importance of cooperation, broad engagement, and early stakeholder involvement for niche growth. To illustrate these intentional efforts, phrases such as "We organized frequent sessions to align goals across stakeholders" (CC2, Interview 7, 2024) were coded.

In order to demonstrate regime stability and resistance to change, MLP identified "Technical Challenges" such as "Energy efficiency optimization," "Seasonal variations," and "Hybrid systems." These challenges emphasize the necessity for AE to compete with or integrate into current technological norms, adjust to environmental trends, and combine with other renewables. 'Economic Barriers' codes, such as 'High connection costs', 'Infrastructure costs', and 'Dependence on subsidies', were drawn from the stability of economic regimes and demonstrate how financial support requirements, established infrastructure, and high initial costs are obstacles to its adoption. Both frameworks are connected by the "Global Learnings" codes "Best practices from pilots" and "Regional adaptations," which stand for SNM's learning processes within niches for improvement and MLP's landscape influence by spreading effective practices and locally customizing global insights, possibly aligning or challenging regime practices.

Furthermore, the inductive technique Table 3 enabled the identification of how stakeholders respond to external changes such as regulatory alterations, as denoted by the code 'Standardized Policies'. Quotes such as "We had to adjust our goals during implementation to accommodate regulatory changes" (PF1,

Interview 5, 2024) demonstrate stakeholders' adaptive responses to regulatory and policy issues. This demonstrates the relationship between policy frameworks and niche development, emphasizing the importance of policy flexibility in supporting innovation (Geels, 2002). By allowing for inductive coding, the study was able to capture these adaptive tactics that would not have been predicted by solely applying deductive codes from MLP, which focuses on the stability of established regimes (Smith et al., 2010).

This dual coding method allowed for a more thorough assessment by ensuring that theoretical expectations from SNM and MLP were taken into account without constraining the empirical data. (Charmaz, 2006), supports this approach, arguing that grounded theory methods are important for discovering new concepts from data, which in this case expanded the understanding of how expectations drive AE transition dynamics in Fryslan. The iterative process of refining codes in interaction with theoretical frameworks as proposed by (Strauss & Corbin, 1998), ensured that the analysis was both theoretically informed and empirically grounded, providing a deep insight into the evolution of expectancies in real-world settings.

A thorough examination of the transcripts was done before the coding process started to become acquainted with the data, the procedure started with a careful reading and rereading of the transcripts. An initial open-coding phase was used to find relevant text segments in the transcripts as the second step in the methodical coding procedure. Following the completion of the initial coding, categories were examined to make sure they were consistent and in line with the study questions. Iteratively, codes were improved, paying close attention to the differences and overlaps between deductive and inductive themes.

Main Code	Sub Code	Description	Framework's Relevance
Technical Challenges (MLP)	Energy efficiency optimization	Maximizing the energy output of AE systems while reducing waste.	(Regime Stability - MLP)
	Seasonal variations	Impact of seasonal water temperature changes on system efficiency.	(Landscape Influence - MLP)
	Hybrid systems	Combining aquathermal systems with other renewable technologies for improved outcomes.	(Niche Innovation - SNM), (Regime Stability - MLP)
Economic Barriers (MLP)	High connection costs	Challenges related to the high upfront and connection costs of aquathermal systems.	(Regime Stability - MLP)
	Infrastructure costs	High costs associated with piping and distribution networks.	(Regime Stability - MLP)
	Dependence on subsidies	Reliance on financial incentives to make AE projects viable.	(Regime Stability - MLP)
Public Engagement (SNM & MLP)	Community workshops	Educating communities on the benefits and functionality of AE systems.	Building public trust in AE (Niche Empowerment - SNM), (Landscape Influence - MLP)
	Education campaigns	Workshops and public awareness programs to inform communities about AE benefits.	(Expectations/Visions - SNM), (Landscape Influence - MLP)
	Transparent communication	Efforts to build public trust and acceptance through clear communication.	(Niche Empowerment - SNM), (Regime Stability - MLP)
	Real-world demonstrations	Using successful pilot projects to showcase AE feasibility.	(Niche Development - SNM), (Regime Interaction - MLP)
Scaling Strategies (SNM)	Regional knowledge exchange	Learning from other provinces to refine AE project implementation strategies.	(Niche Nurturing - SNM)
	Pilot projects	Testing systems on a small scale to reduce risks and build stakeholder confidence.	(Niche Development - SNM)
	Adapting global lessons	Incorporating insights from international projects to local contexts.	(Learning Processes - SNM)
Stakeholder Collaboration (SNM)	Cross-sector partnerships	Collaborations between public and private sectors to share risks and resources.	(Networks/Alliances - SNM)
	Early engagement	Involving stakeholders in the early stages to align goals and mitigate resistance.	(Networks/Alliances - SNM), (Niche Empowerment - SNM)
	Multistakeholder involvement	Engagement of municipalities, private companies, water boards, and communities in AE projects.	(Networks/Alliances - SNM)
Global Learnings (SNM & MLP)	Best practices from pilots	Implementing techniques proven successful in similar regional settings.	(Learning Processes, Niche Nurturing - SNM), (Landscape Influence - MLP)

Table 2: Deductive Codes Table

Main Code	Sub Code	Description	Framework's Relevance
Public Engagement (SNM & MLP)	Building trust	Demonstrating reliability and long-term benefits to gain public confidence.	(Niche Empowerment - SNM), (Landscape Influence - MLP)
Scaling Strategies (SNM)	Standardizing policies	Developing consistent regulatory frameworks to facilitate AE adoption.	(Institutional Embedding - SNM)
Economic Barriers (MLP)	Operational cost challenges	Balancing long-term operational savings with higher initial costs.	(Regime Stability - MLP)
	Upfront investment costs	Significant initial capital requirements for infrastructure development.	(Regime Stability - MLP)
Technical Challenges (MLP)	Filter Ecological Impact	Death of Micro Organisms due to AE systems.	(Landscape Influence - MLP)
	Old infrastructure	Compatibility issues with older buildings and infrastructure.	(Regime Stability - MLP)
	Cold weather performance	Mitigating efficiency losses during colder seasons.	(Landscape Influence - MLP)
Stakeholder Collaboration (SNM)	Community-driven funding	Using crowdfunding or other community-based approaches to finance AE projects.	(Niche Empowerment - SNM), (Networks/Alliances - SNM)

Table 3: Inductive Codes Table

3.5 Validity and Reliability

It is essential to guarantee the validity and reliability of the study procedure. To increase the study's rigour, pilot testing of survey instruments, triangulation of data from several sources, and continual comparison during qualitative data processing will be used. To ensure consistency and coherence throughout the study, continuous comparison in qualitative data processing involves a constant assessment of the qualitative data. To further enhance the validation of both the research approach and the resulting findings, communication and feedback sessions will be held with contact persons from the Province of Friesland (Fryslan, 2022) and the Waterwarmth project (Sea, 2023). Their insights and expertise can help ensure the research methodology remains aligned with real-world considerations and that the findings accurately reflect the context and challenges of aquathermal energy development in Friesland.

Another crucial aspect to consider is the iterative process between the phases of the methodology. Consistent iterations will be carried out among the different phases starting from data collection to data analysis and sample strategy. Going back and forth to refine the data, findings and the answers to each of the sub-research questions, to reach more accurate results.

3.6 Data Management & Ethics

The researchers' top priority was ensuring the study complied with the ethical guidelines established by the Human Research Ethics Committee (HREC) at Delft University of Technology. A comprehensive application detailing the study's goals, how data would be gathered, and participant privacy policies was filed with HREC. The research didn't start until a thorough review by HREC and verification that all legal and ethical requirements had been fulfilled. Participants were properly informed about the purpose of the study and how their data would be used during data collection. They acknowledged receiving this information and their rights by signing an informed consent form. Additionally, participants consented to transcriptions and recordings of their MS Teams interviews. Following the thesis defence, all of the interviews will be safely preserved and will be removed. Throughout the entire investigation, confidentiality was of the utmost importance. The identity of research assistants and interviewees, as well as any information that would identify them, were kept private. Only authorised individuals were able to access the data, and all data treatment was done in accordance with the applicable regulations and guidelines.

To put it briefly, the study gave top priority to ethical conduct and adherence to all regulations. The study was approved at every stage before it started. All along, confidentiality was maintained, and data management protocols were set. The research's ethical conduct was confirmed by the Human Research

Checklist. Please refer to Appendix A for more information on the data management plan, human research ethics checklist and informed consent form.

4

RESULTS

With its numerous lakes, rivers, canals, and waterways, the Netherlands is a land rich in water and offers a special chance to capture aquathermal energy. The nation's shift to a more sustainable heat source could be significantly aided by surface water AE. Aquathermal energy is not a novel idea, but it has been successfully applied in the Netherlands for thirty years. The Paleiswarter district of 's-Hertogenbosch is a good example, as since the early 2000s, approximately 1,500 homes have been heated and cooled by a system that uses thermal energy storage (WKO). Aquathermal energy is now used in only 10,000 residences (Oerlemans, 2020), however the technique is growing in popularity despite this small percentage (Popering-Verkerk, 2021).

Research indicates that AE might supply about 50% of the heating needs in the Netherlands. Presently, most of the approximately eight million residences in the Netherlands still use natural gas as their main heating source. A dramatic change is required under the Climate Agreement, which calls for replacing 1.5 million current houses' natural gas heating systems by 2030 and achieving a full phase-out by 2050. Aquathermy is one of the sustainable heating options that are being quickly investigated and put into practice in order to meet this goal (Oerlemans, 2020).

Although aquathermy is now only found in about 10,000 houses, it is expected to develop significantly. The Sustainable Energy Transition Incentive Scheme (SDE++) opened its doors to projects using waste and surface water for heat extraction in 2020, signalling a turning point. A 5 billion euros are offered by this initiative to encourage and cover the cost of these investments. Furthermore, pilot projects investigating aquathermal energy as a feasible heating alternative, such as ones in Katwijk and Drimmelen, are supported by the Natural Gas-Free Neighbourhoods Program (PAW) (Oerlemans, 2020). Governments are starting to see the benefits of aquathermal energy, and the province of Friesland wants to lead the way in Europe in this area.

4.1 Niche AE systems in Friesland

The following section addresses the first sub-research question

What does the AE niche in Friesland look like?

As mentioned above, Friesland, located in the northern Netherlands, is noted for its abundant water resources. It is a big province with a small population, making it one of the least densely populated regions in the Netherlands (Schure, 2022). Friesland's eighteen primarily rural municipalities present distinct challenges and prospects for energy transition. To address these challenges, Friesland established the Frisian Energy Table (Energietafel, 2022). This platform brings together a variety of stakeholders, including the provincial water board, municipalities, the regional energy distributor (Liander), and civil society organisations. The FET's goal is to collaborate and develop plans for a sustainable energy future in Friesland that are consistent with the Regional Energy Strategy (Fryslân, 2021) objectives.

Aquathermal energy is especially appealing because of the numerous water resources and dispersed villages that dot the Frisian countryside. Heeg, a community in Súdwest-Fryslân, is a prime example of this potential, as they have plans in place as an Energy cooperative to use surface water from the Hegermeer for environmentally friendly village heating (Popering-Verkerk, 2021). Aquathermal energy is already in use in several locations. It frequently affects distinct properties or individual homeowners like Gerrit Hiemstra. For instance, water heat keeps the province's workers warm in the Swettehûs in Leeuwarden, from where forty bridges are run (Bosselaar, 2024). There are presently 26 aquathermy-related projects being developed in Friesland. The province of Friesland completed the 'Missy Wetterwaarmte 2022-2025' a few years ago in an effort to advance it. That mission said that five aquathermal energy plants were expected to be completed

by the following year (2026). Ten thousand commercial buildings and sixty thousand Frisian homes should be connected to community heating systems using surface water heat by 2030 (Bosselaar, 2024).

Currently, there is a noticeable shortage of large-scale, functioning pilot projects in Friesland’s AE sector. The majority of deployments have been limited to individual housings, with the exception of a small installation in Leeuwarden that heats an office building. Despite the limited scope, forward movement is clear. Heeg has made tremendous progress, with the approval procedure finished and excavation already underway: “Heeg already got the approval and started digging.” (PLD). This indicates the potential for growth as smaller projects acquire traction and pave the way for more widespread uses.

4.1.1 The Niche Status of Aquathermal Energy in Friesland

Aquathermal Energy (AE) in Friesland is a niche technology due to its limited adoption and localised implementation in comparison to other established energy technologies and niches in the region. Unlike the well-established use of natural gas for heating, which dominates the present energy regime (Oerlemans, 2020), AE is still in its early phases, with most examples being small-scale or pilot initiatives. For example, although Friesland’s geographical advantages have resulted in numerous photovoltaic (PV) installations and wind energy projects (Schure, 2022), AE’s scale is much less, with only roughly 26 aquathermy-related projects in development (Bosselaar, 2024). This contrasts with the more general adoption of heat pumps, which, while still niche in comparison to gas, have a larger presence in the region since there are stronger national promotions and incentives (Fryslan, 2022).

AE’s niche position is further defined by its community-driven nature, with efforts such as Warm Heeg, which engage local energy cooperatives and aim to provide village-level heating solutions (Warmheeg, 2024). This bottom up strategy differs from larger, more centralised energy initiatives like as natural gas infrastructure or growing electric car charging networks, which receive greater economic and policy support (Energietafel, 2022). The niche of AE in Friesland is further influenced by its reliance on surface water, which is abundant in the region but underutilised for heating as compared to other renewable sources such as solar or wind (Sea, 2023).

Aquathermal energy (AE) is an emerging niche in Friesland, particularly when it comes to stakeholder interactions in comparison to other regional energy sectors. For example, the AquaCOM initiative highlights how the stakeholders in the AE niche work together to provide local heating solutions using water sources through a collaborative framework centred on information exchange and community empowerment. (“AquaCOM”, 2021). In contrast, stakeholders in Friesland’s wind energy sector are driven by established commercial interests and regulatory frameworks, as seen in the development of wind farms like those in the Noordoostpolder, where large-scale investments and government policies play a pivotal role (*Wind Energy Development in Friesland*, 2019). In contrast, the stakeholder interaction in AE differs significantly from that of Friesland’s more advanced solar photovoltaics technology. A competitive market environment is fostered by the well-defined supply chain of solar energy, which includes manufacturers, installers, and consumers (Janssen & De Vries, 2020). In contrast, AE stakeholders are still defining their roles, focussing on innovation and local governance to produce comparable models that demonstrate the niche’s distinct growth trajectory within Friesland’s energy landscape.

Technologically, AE systems are less developed in Friesland than other renewable energy technologies. For example, the region has experienced significant innovation in biomass and geothermal energy, with established research and infrastructure (Popering-Verkerk, 2021). However, AE has technological constraints like seasonal water temperature fluctuations and the necessity for specialised heat exchangers (Goossens et al., 2021), which are less severe in other renewable technologies.

In summary, AE’s niche status in Friesland is distinguished by its small scale, community-oriented approach, and the special technological modifications necessary, which set it apart from both the widespread fossil fuel-based heating regime and other renewable energy niches. This situation emphasises the importance of strategic management in fostering growth in accordance with local conditions and resources, as illustrated in the application of SNM and MLP frameworks (Hoppe et al., 2024).

4.1.2 Key Stakeholders

Numerous parties are involved in large-scale AE projects, and each has specific duties and obligations. The eight main stakeholders in AE are the source holder (water boards or Rijkswaterstaat), network operator, energy or heat company, financier, housing associations/utility building owner, builder/contractor, municipality, and province, according to Netwerk Aquathermie (Aquathermie, n.d.), a Dutch knowledge-sharing network. Moreover, according to Van Popering Verkerk, participation is also possible from citizens and citizen corporations (Popering-Verkerk, 2021).

Public-private cooperation is essential for the successful use of AE (Aquathermie, n.d.) (Popering-Verkerk, 2021). Although precise roles haven't been established yet, Van Popering-Verkerk discovered areas in which stakeholders usually participate (Popering-Verkerk, 2021). These positions fall into one of two categories: those connected to the "process" (project development) or the "chain" (supply). Stakeholders may participate in one or both. As seen in the Figure 9 the defined functions inside the chain are "no role," "partial role," or "integral role." Process responsibilities include "managing" (project leadership), "collaborating" (active project contribution), "supporting" (stakeholder unity and information exchange), and "ensuring" (Project legitimacy) (Popering-Verkerk, 2021) (van de Witte, 2023).

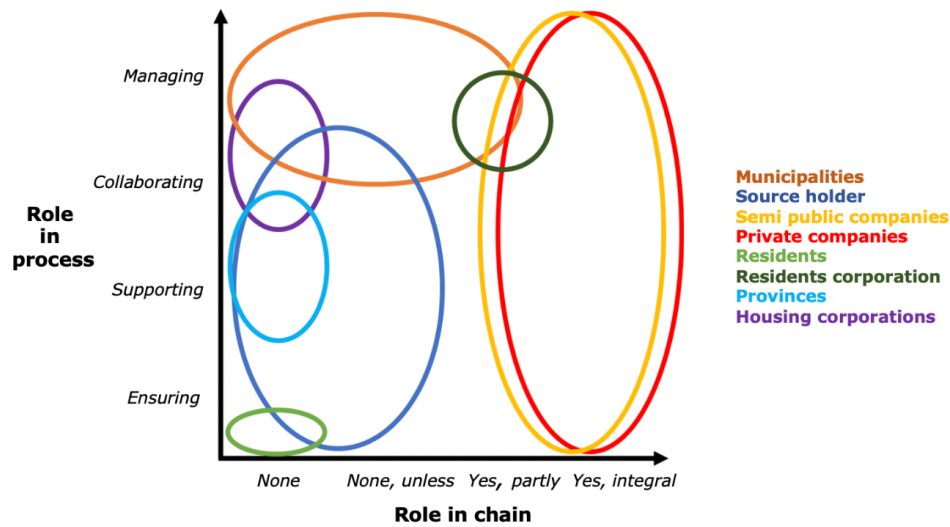


Figure 9: Stakeholder's Roles in AE (van de Witte, 2023) adapted from (Popering-Verkerk, 2021)

Usually, municipalities coordinate the effort and bring all parties together (Popering-Verkerk, 2021). Additionally, they grant permits and offer assistance in the form of labour and financial aid. The dynamics of the market determine their participation in the supply chain. Municipalities might refrain from direct participation if the market meets the chain's requirements. But when there are gaps in the market, they become more involved (van de Witte, 2023). Water boards or Rijkswaterstaat are the usual source holders, who are always involved because of the water supply (Popering-Verkerk, 2021). In certain circumstances, private businesses or municipalities may also be source holders. Their main responsibility is to protect water interests and provide information on ecosystems and water systems in order to ensure and support the process (Popering-Verkerk, 2021) (van de Witte, 2023).

AE initiatives can involve both public and commercial organisations in different capacities (Popering-Verkerk, 2021). These could include financial institutions, energy providers, network operators, and contractors/builders (Aquathermie, n.d.). Businesses with an interest in the supply chain frequently begin as collaborators and then transition into coordinators (van de Witte, 2023). Although residents are rarely involved in the decision-making process from the outset, they may be involved when they receive a formal "offer" (Popering-Verkerk, 2021). Nonetheless, there are initiatives started by people themselves, in which locals establish energy cooperatives, collaborate, and even oversee certain segments of the AE chain (Popering-Verkerk, 2021) (van de Witte, 2023).

The province and its level of involvement varies greatly (van de Witte, 2023). While some provinces play a more passive role, others serve as co-financiers, knowledge-sharers, or facilitators. But for AE systems, licensing authority is held by all provinces (Popering-Verkerk, 2021) (van de Witte, 2023).

Finally housing associations collaborate in the process, as their structures have the potential to benefit from aquathermal heating (Popering-Verkerk, 2021). In their neighbourhoods, they tend to collaborate with AE initiatives that involve resident engagement, business case building, and feasibility studies (Popering-Verkerk, 2021) (van de Witte, 2023).

1. **Dutch Ministry of Economic Affairs and Climate Policy (EZK)** Responsible for developing national policies on energy security and sustainability goals (EZK, 2024). They oversee funding programs for renewable energy projects that accord with these objectives, such as the Klimaatfonds (Climate Fund) (EZK, 2024).
2. **Ministry of Infrastructure and Water Management (I&W)** Oversees national water management initiatives and may be concerned about AE's influence on water supplies (Waterstaat, 2023). They work with water authorities such as Wetterskip Fryslân to promote sustainable water usage practices (Waterstaat, 2023).
3. **Friesland Provincial Government:** The national Ministry establishes broad environmental goals for clean air, water, and soil throughout the country. The 12 provinces then use these national objectives to develop individual regional plans. These plans oversee development (housing, factories, and stores) in cities and towns while also managing pollution from cars, factories, and other sources to guarantee a safe environment (Waterstaat, 2012). Provinces have the authority to give environmental permits for projects, limiting noise and pollution. They also enforce environmental regulations for large corporations and actively encourage renewable energy (Waterstaat, 2012). Interviews with officials can reveal environmental and social factors related to AE development. Also specific permitting requirements and potential barriers to developing AE projects in their regions. Existing local infrastructure could be connected with AE systems to maximise resource utilisation.
4. **Municipalities:** These municipal and town governments establish their own regulations to enforce national environmental policies (Waterstaat, 2012). They have the legal authority and budget to carry out and enforce these choices, which include separated trash collection, proper hazardous waste disposal, clean air, and noise control. Municipalities can also partner with water boards to improve water quality and wastewater treatment (Waterstaat, 2012). Municipalities are also accountable for engaging residents and promoting openness (Waterstaat, 2012). Interviews with municipal officials can give insight on water treatment and waste treatment as well. They can also help with the most effective ways for communicating with communities and addressing their concerns about AE projects.
5. **Water Governance & Authorities (Wetterskip Fryslân)** Manages and maintains surface water quantity across Friesland, issues permits for water use and potential environmental implications of projects and monitors the surface water quality for its chemical and biological composition (Waterstaat, 2012). Interviews with water board specialists can shed light on how AE systems may affect water quality, quantity, and ecological health in certain bodies. What are the regulations for sustainable AE development that addresses water usage and environmental criteria. And what are the strategies for developing and managing AE systems with minimal water consumption and ecological impact as well as existing water quality data and monitoring procedures
6. **Regional grid operator:** As a regional grid operator in Friesland, liander is actively involved in extending and maintaining the electricity and gas networks to help the region transition to sustainability (liander, 2024). As the energy landscape changes, it will be helpful to learn about how this could be integrated into their service offerings.
7. **Energy Provider** Essent is a significant energy company in the Netherlands, delivering electricity, gas, and other energy services to both residential and commercial users. Essent is the typical energy provider in Friesland, specifically in Leeuwarden (Essent, 2024).
8. **University of Groningen's Energy & Sustainability research** This research can benefit from

the participation of universities and research centres with experience in water and renewable energy, such as the Energy & Sustainability research group at the University of Groningen (Esrig, 2024). One way to learn more about their current body of knowledge regarding AE is to conduct an interview with a researcher who specialises in water management, renewable energy, or a related topic.

9. **Wetterwaarmte** Wetterwaarmte is a regional program that promotes the use of AE in Friesland. They promote the "Wetterwaarmte" approach (Sea, 2023). While they typically support aquathermal energy development, they may have particular interests or areas of expertise, as well as concerns that can help this research.
10. **Residents** Residents of Friesland will be the most immediately impacted by the implementation of AE systems in their areas. Understanding their views is critical for successful project execution. Focus groups or individual interviews with residents from various backgrounds and places in Friesland can help understand their concerns and perspective
11. **Property owners near potential installation sites** Individuals or businesses who own land or property near proposed AE installations may be concerned about the visual impact on their property values, as well as potential noise pollution during building and operation. They may be concerned about changes to their land usage or access to waterways.
12. **Users of Waterways** People who utilize waterways for boating, fishing, or swimming may be concerned that AE installations would disrupt their leisure activities or constitute a safety risk. They may also be concerned about the environmental impact of aquathermal energy systems on fish populations and water quality.

4.1.3 Stakeholders' Collaboration

A stakeholders map was created during the research process to show the intricate web of parties involved in Friesland's aquathermal energy (AE) initiatives Figure 33. Multiple participants were asked to comment on this preliminary established map during the interviews (MOL, Interview 3, 2024), (MFM, Interview 1, 2024), (CC1, Interview 2, 2024), (MMD, Interview 12, 2024), (MKB, Interview 13, 2024), sharing their perspectives on the functions, connections, and influence of different stakeholders. One of the interviewees contributed to a preliminary collective AE systems map Appendix C. The final map is the outcome of a combination of all these. The stakeholders' map was improved and validated through an iterative feedback approach, guaranteeing that it appropriately depicts the dynamics of AE development in Friesland. These inputs are combined in the final map Figure 10 to produce a thorough visual depiction of the stakeholders, the solid lines represent a direct connection and the dotted lines represent an indirect connection but yet influence the overall dynamics.

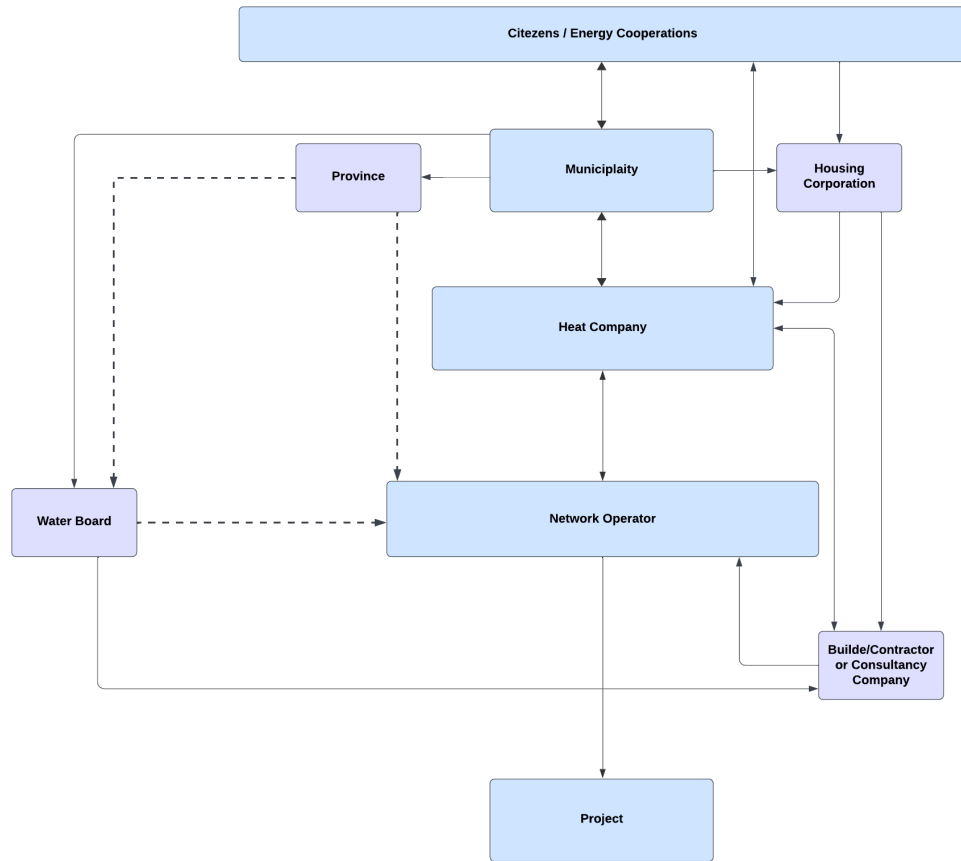


Figure 10: stakeholder's map in AE

1. Water Board Collaborations

- With Citizens/Energy Cooperatives: To guarantee adherence to environmental laws, the Water Board offers permits and ecological supervision. "The Water Board's involvement is critical for permitting and addressing environmental concerns," said (CC1, Interview 2, 2024).
- With Private Companies: To provide technical and ecological advice services, the Water Board works with private businesses. (CC1, Interview 2, 2024) noted, for example, that "The water board often consult private firms to assess water usage feasibility for aquathermal systems."
- With Municipality: To ensure that projects adhere to regional water policy, the Water Board works with municipalities to coordinate regulations.
- With Province (Indirect Relationship): The Water Board aligns its operations with the Province's broader environmental and energy transition goals. Although the relationship is not direct, the Province's policies significantly influence the Water Board's priorities and regulatory focus. This connection ensures that local water management strategies contribute to the overarching sustainability agenda (Waterschap, 2003).
- With Network Operator (Indirect Relationship): The Water Board's management of surface water resources indirectly supports the Network Operator's logistical planning for energy distribution. Through mediated coordination by municipalities or project intermediaries, the compatibility of water-based energy sources with network operations is ensured (Meijerink, 2001).

2. Energy Cooperatives

- With Municipalities: Collaborate closely with municipalities to involve the community, obtain regulatory permissions, and provide financial support. According to (PLH, Interview 11, 2024), "The municipality has been instrumental in facilitating permits and subsidies."
- With Heat Companies: Manage the technical design and operations of heat systems in conjunction with heat companies. It was highlighted by (PLD, Interview 9, 2024) that "Our partnerships with heat companies ensure technical reliability."
- With Builders/Contractors: When implementing a project, collaborate with builders or contractors to make sure installations satisfy community demands.

3. Municipality and Province

The municipality facilitates multi-regional funding and learning by coordinating local initiatives with the Province's more general priorities. It was observed by (PF1, Interview 5, 2024) that "The Province's support facilitates scaling by connecting us to European frameworks."

4. Social Housing Corporations

Adopt aquathermal systems for housing developments in partnership with energy cooperatives to meet the long-term demand for sustainable heat. According to (MKB, Interview 13, 2024), "Housing corporations are integral to creating viable business cases." To guarantee heat is supplied, they also collaborate with heating companies.

5. Heat Company and Network Operator

In order to ensure the smooth delivery of energy, the Heat Company collaborates with the Network Operator to manage system logistics. (CC2, Interview 7, 2024)

4.2 Theoretical Frameworks Application

The next section looks deeper into Wetterwaarmte's potential using the Multi-Level Perspective (MLP) and Strategic Niche Management (SNM) explained in Chapter 2. Both can help shed light on how sustainable innovations arise and develop. MLP looks at the large picture, exploring the ways in which existing systems, niche innovations, and broader societal trends combine to convey transformation. SNM, on the other hand, focuses on the specific processes within niche communities, where new ideas are nurtured and developed.

4.2.1 MLP Framework Application

The MLP framework will assist in identifying key opportunities and challenges for scaling surface water AE in Friesland by examining the interaction of the Landscape, the regime, and the Niche to gain a comprehensive understanding of the socio-technical system (Cherp et al., 2018). In this context, the research can use MLP to identify the problems provided by the current rural regime (lack of awareness, reliance on conventional systems) and determine how AE, as a niche technology, might overcome these obstacles (Geels, 2002), (Hoppe et al., 2024), (Smith et al., 2005). The following section is dedicated to address the second sub research question:

How to analyse Friesland's existing heating system regime in the context of MLP framework?

1. Landscape

This section will present the landscape enabling factors which are (Earthquakes in the Groningen Region, Climate Change and COP21 Paris Agreement (2015), Russian Invasion of Ukraine and Surging Gas Prices (2022) and Cultural Shift Toward Green Energy Systems and Energy Cooperatives) and also the inhibiting factors which are (Partial Reimbursement for Surging Gas Prices, Restrictive Legislation and Permit Systems and the political stance on climate change)

The transition from conventional heating technologies, mainly natural gas, to more sustainable alternatives, such as aquathermal energy, is influenced by a complex interplay of elements, as revealed by an analysis of Friesland's current heating system using the Multi-Level Perspective (MLP) framework.

Broader sociopolitical and environmental forces, especially national efforts to reduce greenhouse gas emissions and the European Union's climate goals, influence Friesland at the landscape level.

Decades of natural gas production have made the Groningen region's frequent earthquakes worse, raising political and popular awareness of the dangers of relying too much on natural gas. In response, the Dutch government has launched nationwide initiatives to move away from natural gas since 2018. Initiatives such as PAW (Programma Aardgasvrije Wijken) have pushed for the use of heat pumps and thermal insulation, as well as neighbourhood-scale testing of alternative heating methods, such as AE. Decentralised control is driving the heat transition, and municipalities are responsible for creating implementation plans and localised "heat visions" (TVHs). As part of larger initiatives to lessen dependency on natural gas, this decentralised strategy gives local governments the authority and resources to test AE projects.

In addition, the Paris Agreement established a global framework to combat climate change, and its incorporation into Dutch climate policy has been critical in facilitating the deployment of renewable energy technologies, particularly aquathermal energy. The Netherlands incorporated COP21 concepts into projects such as the "Green Deal Aquathermie," which especially supports AE as part of its renewable energy transition. Regional Energy Strategies (RES) have further decentralised governance, allowing municipalities to play an important role in promoting AE adoption by connecting it with larger climate goals. This policy framework establishes clear institutional support for renewable energy projects while also legitimising local AE innovation in line with national and international climate ambitions. In the statement, "We do need some replacement, so some alternatives and that's individually with heat pumps or mostly collective systems", (MOL, Interview 3, 2024) of the municipality of Leeuwarden emphasises the urgency of phase-outs of natural gas in order to achieve the Netherlands' aim to becoming a carbon-neutral economy by 2050. This also demonstrates the growing awareness among municipal authorities of the need for fossil fuel substitutes. Local actors are forced to innovate and adapt against the backdrop created by the landscape context, particularly in light of the increased public opinion towards climate change in recent years. This change in public perception is important because it encourages interested parties to look for environmentally friendly heating options that complement broader environmental objectives. However, (PF1, Interview 5, 2024) points out that the political situation is also changing, pointing out that the present government has shifted away from sustainability programs, which may impede advancement. According to (PF1, Interview 5, 2024), "the current government has shifted focus away from sustainability," which may have an effect on aquathermal project funding and support. For stakeholders attempting to manage the transition to renewable energy sources, this change in political intent may cause uncertainty. This political change has important ramifications since it may result in a lack of consistency in policy support, which would make it difficult for local actors to make sustained investments in sustainable technologies.

Additionally, outside variables like the state of the economy and developments in technology have an impact on the landscape level and can help or hinder the shift to more environmentally friendly heating options. The ongoing crisis in Ukraine has affected global energy markets, resulting in a significant increase in natural gas prices. As individuals and businesses strive to lessen their dependency on expensive natural gas, this has opened up a window of opportunity for alternative heating systems such as AE and heat pumps. The rising market demand for heat pumps and insulation has fuelled interest in renewable heating systems, such as AE, as a long-term and cost-effective alternative. This geopolitical crisis has unintentionally hastened the energy transition by leaving traditional energy sources economically unsustainable for many.

Although growing natural gas costs have created prospects for renewable energy adoption, the government's partial reimbursement programs have discouraged houses and businesses from investing in alternative systems such as AE. By subsidising gas prices, the government unintentionally lessens the economic urgency of switching to heat pumps or AE systems. This results in a gap between short-term economic relief measures and long-term climate goals, delaying the adoption of renewable technologies despite their potential benefits. (CC2, Interview 7, 2024), for example, points out that "there needs to be a bigger tax shift and more promotion of heat pumps" because "the gas price can be quite low compared to electricity and there needs to be a bigger tax shift and more promotion of heat pumps".

This demonstrates the potential financial difficulties that can occur when fossil fuels maintain their competitive pricing, hindering renewable alternatives adoption.

Moreover, the emergence of energy cooperatives can be viewed as a key enabler. In this regard, energy cooperatives are bottom-up projects that arise in reaction to more general social factors like energy security and climate change. The Netherlands' population has grown more aware of and supportive of renewable energy systems over time, indicating a cultural shift in line with the demands of sustainability and the objectives of the energy transition. This change is partially a reaction to the ineffectiveness of the market and government in accomplishing these objectives, which has made room for alternate energy sources (PLB, Interview 4, 2024). Building public trust and involvement requires supportive legislation, sufficient financing, and efficient communication tactics for these programs to succeed. (PLB, Interview 4, 2024)

2. Regime

When it comes to the regime level, natural gas, which has long been the main source of heating both homes and businesses, dominates Friesland's heating system. In the context of the Netherlands' energy transition, the congestion issue is a major obstacle that has an impact on the development of sustainable energy systems. "The main reason there is the congestion problems we have on the electricity network in the Netherlands" is (PLD, Interview 9, 2024)'s statement in reference to this topic. PLD also adds that "We cannot be connected to the grid for a common collective energy heat system for the village until 2029" because of inadequate infrastructure, he explains, emphasising that even with a strong business plan, the power grid's capacity can be a significant barrier. As (PLD, Interview 9, 2024) notes, "we are electrifying our energy demands from fossil fuels to electricity too quickly," indicating that this congestion is a national problem rather than merely a local one. The construction of the required infrastructure, such as transformers and power cables, is not keeping up with the sharp rise in electricity use. It was pointed out that "they have to install more than 10,000 new transformers in rural areas to distribute the large amount of electricity we need for the future". This congestion issue has significant ramifications since it makes it more difficult for cities to successfully carry out their energy transition plans. The shift to sustainable energy sources faces significant obstacles in by the lack of sufficient infrastructure to meet the rising demand for electricity, which delays the implementation of regional energy projects and increases dependency on conventional energy suppliers.

(a) Policies and Regulations

There is a lot of resistance to change in the current infrastructure, such as heating systems and gas pipelines. "The tricky part is... the realisation of a district heating network because it's more complex," as (PF2, Interview 6, 2024) notes. The necessity to coordinate multiple stakeholders—such as municipalities, energy cooperatives, and water boards—each with distinct interests and regulatory frameworks is the source of this complexity. As (PF2, Interview 6, 2024) points out, "the water body is responsible for water quality... they would say no, we need a lot of research." This caution is often reflected in the governance mechanisms in place, especially when it comes to environmental implications. Due to the intricate web of rules and approvals that stakeholders must understand, this regulatory caution may impede the quick adoption of innovative heating technologies like aquathermal energy.

However (WWB, Interview 10, 2024) claims that the idea that these rules are excessively strict is not totally true "That's not true. We are very clear in what we do not want and what we do want". This shows that the regulations are based on specific permit requests, which make it clear what is needed, rather than being arbitrary. "If you want to do something with that water, we want you to rule out that there are no negative effects," WWB adds, explaining that the water board's job is to make sure that any project doesn't have a detrimental influence on the quality of the water. (WWB, Interview 10, 2024) stresses that the board has obligations that must be fulfilled, especially with regard to water quality, and that they are not being strict for the purpose of being harsh. Furthermore, he contends that a misinterpretation of the rules could be the cause of the impression of strictness. (WWB, Interview 10, 2024) states, "If you know what you're doing, then you know certain conditions you have to take into consideration, then you

can engineer around that” This implies that projects can be planned to meet the water board’s requirements without major obstacles if the rules are understood and appropriate planning is done. (WWB, Interview 10, 2024) argues that although while the water board has explicit rules, these should not be seen as too strict; rather, they are essential steps to preserve water quality and guarantee that projects are carried out responsibly.

Implementing AE systems is significantly hampered by restrictive laws and disjointed permitting procedures. Multiple permits from various policy sectors are frequently needed for AE projects, which might cause delays and administrative challenges. Both commercial and municipal players are deterred from pursuing AE projects by this regulatory complexity. Furthermore, scaling such systems is challenging due to the absence of simplified frameworks for AE-specific legislation. For instance, different municipalities have different ecological and procedural standards, which makes implementation more difficult and increases the time and expense of developing an AE project. This emphasises how policy frameworks must be more flexible and integrated in order to support the implementation of AE. Showing that the existing regulatory framework is still developing and might not be sufficient to meet the demands of AE projects. ”The water boards are a bit hesitant when it comes to large scale systems” has also been mentioned by (CC2, Interview 7, 2024) , which illustrates the regulatory organisations’ cautious approach. Additionally, (CC2, Interview 7, 2024) mentioned that ”There is just a gap of knowledge between what we want to install with the extraction of the heat from the water and what the consequences could be for the ecological system”. Since stakeholders are frequently needed to carry out in-depth research and monitoring prior to permits being granted, such uncertainty adds to the restrictive nature of the permitting process.

(b) Technology and Market

The majority of installations are individual systems, which restricts the scalability of aquathermal energy. Another characteristic of the current heating regime is the absence of collaborative heating systems. According to (MOL, Interview 3, 2024) , ”it’s not a technical challenge; it is more a financial challenge”. ”The amount of money people need to pay to get connected, sometimes €20,000 or €25,000, is a major deterrent for inhabitants.” said (WWB, Interview 10, 2024), highlighting this problem. This illustrates how consumers find it challenging to move to innovative technologies like AE due to economic lock-ins caused by hefty upfront prices.

In rural regions like Friesland, the difficulties and expenses of piping pose serious obstacles to the development of renewable energy alternatives. The most costly portion of switching to aquathermal energy is the infrastructure needed for a heating network, especially the pipes. For instance, ”in the village of Balk, the demand for warmth necessitates approximately 14 kilometres of central piping, which can cost around €1,000,000 per kilometre,” as stated by (PLB, Interview 4, 2024). According to (PLD, Interview 9, 2024), ”the warmth demand is spread over a larger space compared to urban settings”. A centralised heating system for every home is therefore not financially feasible due to the requirement for extensive piping, which raises prices. According to (PLB, Interview 4, 2024) and (PLD, Interview 9, 2024) Communities urgently need to establish their own energy supplier businesses in light of these budgetary limitations. This strategy would lessen reliance on commercial providers, who frequently have dominant control over pricing, and enable entities to determine their own rates. ”The establishment of a local heating company is seen as essential to ensure that the community can manage its energy needs effectively and sustainably,” as noted by (PLB, Interview 4, 2024). However, ”the initial investment required to set up such a company is substantial, and many local governments are hesitant to take on the financial risks associated with these projects,” (PLD, Interview 9, 2024) explains.

In this context, the village of Balk has already taken proactive steps by initiating its own heating company to support the development of aquathermal energy projects. The decision to create a heating company was made during a member meeting of the Energy Cooperative, where it was stated, ”the Energy Cooperative will raise a heating company” (PLB, Interview 4, 2024) This initiative is essential for ensuring that the community can manage its energy needs effectively and

sustainably.

Additionally High connection prices and considerable infrastructure investments pose significant economic barriers, making affordability a top priority for stakeholders. However, novel finance approaches, such as crowdfunding, provide promising possibilities. (PLB, Interview 4, 2024) emphasised this strategy: "We have started a crowdfunding campaign to involve local residents in funding the project." Furthermore, as (CC2, Interview 7, 2024) noted, "in Gelderland, the province has made a sort of startup bank... set up to stimulate initiatives for the heat transition". This startup bank provides vital funding and support for the development of aquathermal energy projects, acting as a safety net for projects similar to the one in Balk.

This demonstrates the substantial financial obstacles that need to be removed in order to speed up the switch to more environmentally friendly heating options. Many prospective users are put off by the high expenses of aquathermal systems, especially in an area with comparatively weak economic conditions. Since many homeowners do not have the funds to invest in new technologies, financing these systems is a crucial difficulty that could result in a reliance on conventional heating techniques. Additional as discussed above difficulties arise when integrating aquathermal energy systems into already existing heating networks. (PF2, Interview 6, 2024) points out that "finding a way to do district heating in smaller areas is gonna be really a tipping point for us to develop aquathermal energy in Friesland".

Moreover, the salinity of Friesland's water bodies presents a significant technological problem for aquathermal energy (AE) systems, as underlined in an interview with PF2, who stated that "the larger part of Friesland is salt water" (PF2, Interview 6, 2024). This high salt level can accelerate corrosion in heat exchangers and pipes, reducing system performance and increasing maintenance costs. To mitigate these consequences, the environment necessitates the development of specialised technologies such as corrosion-resistant materials or novel heat exchanger designs. This salinity issue not only complicates the technological element of AE, but it also shapes the market by creating a need for saline-specific solutions, potentially increasing the cost and complexity of establishing AE systems in Friesland. This scenario highlights the urgent need for technological breakthroughs to enable the widespread acceptance and scalability of AE in this unique setting.

3. Niche

Emerging techniques and technologies, such aquathermal energy systems, are being developed and evaluated at the niche level in the MLP framework. Compared to more well-known alternatives like heat pumps, these systems are still regarded as niche technology in Friesland and have not been widely adopted. Friesland is trailing behind in the adoption of these solutions, as stated by MOL' observation that "it's a niche technology... heat pumps are mostly common" in other regions. The Missy Water Warmth program, which involves numerous communities and partners, is one of the initiatives the province has started to raise awareness and ease the transition to aquathermal energy. But as (MOL, Interview 3, 2024) pointed out, the systems' financial sustainability continues to be a major obstacle: "how do you finance the system... people who don't have that... how can you pay?". This claim emphasises how important it is to have financial tools that can encourage the usage of aquathermal energy systems, especially for low-income households, as (MOL, Interview 3, 2024) stated "We are more in a poorer region of the Netherlands, and of course a lot of people can't afford to pay the investments".

Additional difficulties arise when integrating aquathermal energy systems into already-existing heating networks. (PF2, Interview 6, 2024) points out that "finding a way to do district heating in smaller areas... is gonna be really... a tipping point for us to develop aquathermal energy in Friesland". In order to scale up aquathermal energy systems, it is crucial to create efficient district heating solutions that can service smaller populations. Given the natural resources of the area and the dedication of local stakeholders to seek sustainable energy solutions, Friesland has a substantial potential for aquathermal energy. However, innovative governance, public involvement, and funding will be needed to address the integration and scaling issues.

Frameworks for governance and policy play a critical role in encouraging the growth of aquathermal energy systems in Friesland. With an emphasis on stakeholder engagement and community involvement, the province has launched a number of measures to promote renewable energy. According to (PF1, Interview 5, 2024), "we have a regional policy plan... in which we work a lot with different stakeholders". The current political environment presents difficulties, too, as support for sustainability programs has decreased as a result of recent changes in the government's priorities. According to PF1, "the current government has shifted focus away from sustainability," which may have an effect on aquathermal project funding and support. The success of aquathermal energy projects is greatly influenced by public engagement and acceptance.

Although Friesland inhabitants are becoming more interested in sustainable energy options, wider adoption may be hampered by the high upfront costs and ignorance of aquathermal technology. "The Frisians like to do it themselves and they think we do have a lot of surface water, so why not could aquathermal energy be a solution?" is something (MOL, Interview 3, 2024) observes. Increased acceptability of aquathermal energy systems can be facilitated by utilising the local pride and commitment to ecological practices. Energy cooperatives and other community-driven projects are essential to this process because they give locals the knowledge and assistance they need to switch to renewable energy sources

In summary, applying the MLP framework to the analysis of Friesland's current heating system regime reveals a complex environment where established natural gas infrastructure, new aquathermal technologies, and sociopolitical influences interact. There are many obstacles in the way of the shift to sustainable heating solutions, such as cost constraints, regulatory diligence, and the requirement for efficient stakeholder cooperation. However, considering the natural resources of the area and the dedication of local stakeholders to seek sustainable energy solutions, Friesland has a substantial potential for aquathermal energy. For aquathermal energy systems in Friesland to successfully scale, these factors can be resolved through innovative governance, public involvement, and financial assistance.

4.2.2 SNM Framework Application

SNM principles will lead the development of potential tactics that can be used for overcoming resistance from the current system and navigating policy frameworks. This research will look into how stakeholders are currently using knowledge exchange, network development, and policy lobbying to encourage wider adoption of surface water AE. Analysing existing practices allows us to find areas of strength and potential limitations in these tactics. This will help to shape recommendations for how stakeholders may make the best use of these tools. Understanding the present dynamics within the AE niche, as well as identifying areas for improvement, can help unlock the collective power of this socio-technical system and pave the road for wider adoption. The following section will tackle the third sub research question.

How may SNM principles be applied to AE niche in Friesland and ultimately scaling AE?

It is crucial to take into account the distinct socioeconomic and environmental context of the area in order to examine how Strategic Niche Management (SNM) ideas might be applied to the Aquathermal Energy (AE) niche in Friesland and eventually aid in its scaling. With more than 400 villages and populations ranging from 500 to 8,000, Friesland is known for its rural environment. Particularly when it comes to community heating solutions, this demographic composition offers both benefits and constraints for the deployment of AE systems.

1. Shared Vision and Stakeholder Engagement

The creation of a common vision among stakeholders is a fundamental component of SNM. Warm Heeg and other energy cooperatives in Friesland have developed a village vision that prioritises community involvement and energy neutrality. According to (PLH, Interview 11, 2024), "Warm Heeg started 7 years ago with the village vision, energy neutrality and the project WH is part of that vision". This vision is a live framework that directs the cooperative's operations and encourages a sense of ownership among its members; it is not just a formal statement. In order to operationalise this goal, the cooperative's team which is made up of people with a variety of backgrounds in networking, finance,

and environmental management, is essential.

One of the distinguishing features of this common vision is its ability to bring together a diverse range of stakeholders, from local governments and cooperatives to social housing providers and technical specialists. This collaboration is critical for overcoming the multiple hurdles of shifting to renewable energy (Biresselioglu et al., 2024). Municipalities provide legislative guidance and infrastructure support, while energy cooperatives bring grass-roots engagement and locally tailored solutions, resulting in a balanced and inclusive approach.

Stakeholder engagement is a critical component of putting this vision into action, as it goes beyond formal positions to establish trust and long-term commitment. (PLB, Interview 4, 2024) explained how cooperatives empower communities, saying, "Our goal is to empower local communities to take control of their energy needs while also contributing to broader sustainability goals." This empowerment instils a sense of ownership in inhabitants, allowing them to actively participate in the region's energy transition (Biresselioglu et al., 2024). Transparent communication strengthens this trust. (PLH, Interview 11, 2024) points out that tools like price calculators solve affordability concerns: "Transparent calculation, have a price calculator on the website." Such methods guarantee that stakeholders are informed and confident in AE systems' viability.

Education and outreach programs are another pillar of stakeholder engagement. (PLH, Interview 11, 2024) detailed a six-week education campaign to raise awareness about AE: "They have had an education campaign for 6 weeks, delivering brochures to people, each household." These initiatives ensure that all stakeholders, including community people, understand the benefits, limitations, and potential of AE. These efforts encourage widespread support for AE projects by explaining technology and eliminating myths.

Stakeholders also work together to overcome hurdles to AE implementation. Regulatory concerns, for example, are addressed collectively to ensure that policies are consistent. (PF1, Interview 5, 2024) stressed the importance of consistent regulatory support: "Subsidies for district heating could help bridge the gap and make these projects more financially viable."

Several participants agreed that energy cooperatives play an important role in the development of AE niches. According to (CC2, Interview 7, 2024), "Energy cooperatives act as the glue between citizens, municipalities, and technical experts." (PLB, Interview 4, 2024) stressed their significance, saying, "Without the energy cooperative, this project wouldn't have gotten off the ground." These can cooperatives promote collaboration, align stakeholder interests which can help in the execution of AE projects, highlighting their critical role in niche governance.

The significance of placing AE within broader regional and national sustainability goals was emphasized by a number of interviewees. (WWB, Interview 10, 2024) clarified, "This project isn't just about energy; it's part of a larger push towards sustainable living in our region." According to (PLD, Interview 9, 2024), "Linking AE to climate adaptation strategies makes it easier to get buy-in from policymakers." Niche actors strengthen the legitimacy of their initiatives and match them with policymaking agendas by integrating AE into larger sustainability and climate adaption narratives. This makes it simpler to obtain institutional and financial support.

According to the transcripts, controlling stakeholder expectations is essential to preserving agreement and averting disputes. (PLB, Interview 11, 2024) said, "We have to manage expectations carefully—some stakeholders want immediate results, while others prioritize long-term sustainability." According to (MFM, Interview 1, 2024), "Balancing the technical feasibility and the expectations of policymakers is a constant challenge." In order to ensure that all stakeholders remain committed to the project's success, these insights highlight the necessity of strategic communication in bridging the gap between immediate demands and long-term objectives.

In Friesland, the process of voicing and shaping expectations is being done through knowledge exchange platforms involving researchers, policymakers, management agencies, and the general public. There are workshops and training sessions to educate stakeholders about the potential of aquathermal energy. However, there is still a lack of public awareness of what aquathermal energy is. Many people are still

unfamiliar with the concept and view it as unproven ” it is unknown, it is for the far majority of the people, unproven.” (PLD, Interview 9, 2024). Additionally, there are concerns that if pilot projects fail, this could create conflict in the villages ”At the same time, this can also be dangerous, because if these projects fail, it can also lead to a lot of conflicts” (PF1, Interview 5, 2024). SNM can bridge this gap by creating more platforms for open communication and collaboration. This involves engaging the community through public websites with frequently asked questions and examples of successful projects, and addressing concerns about the environmental impacts, lifetime of the heat pumps, and other factors (CC1, Interview 2, 2024). In Denmark, for instance, energy communities have been successful in transforming projects into ”Yes, in my backyard” situations rather than facing resistance (MMD, Interview 12, 2024). This highlights the importance of involving local communities and making them active participants in the energy transition.

2. Learning Processes and Knowledge Sharing

The ongoing learning through experimentation and user interaction. Pilot programmes are key tools in this process. By implementing and monitoring small-scale projects in rural areas, useful data can be gathered to inform future development and optimise the technology for real-world applications. Additionally, user interaction promotes social learning by addressing public concerns and gathering feedback to improve the technology and increase social acceptance (Raven, 2005), (Hoppe et al., 2024).

In order to learn from other initiatives and steer clear of typical problems, energy cooperatives in Friesland have actively participated in knowledge-sharing networks like Waterwarmth and Energie Samen. Stakeholders can improve their tactics and adjust to new problems thanks to this collaborative learning technique. As a useful tool for ongoing development, Warm Heeg, for instance, keeps a logbook to record experiences and lessons discovered during project phases (Warmheeg, 2024).

Furthermore, awareness and education are significantly important (Falkner, 2016). Many locals are ignorant of AE technology, which can cause them to be sceptical and reluctant to use collective systems. According to (MOL, Interview 3, 2024), ”A lot of people don’t know technical factors of heat pumps and aquathermal systems... it’s more a case of people don’t know exactly what it is”. Warm Heeg has responded to this by launching educational initiatives to educate the public on the advantages and operation of AE systems, which helps to allay fears of the unknown.

The current lack of operational activities in the area highlights the pressing need for a successful pilot project in Fryslan. ”We need example projects, so we need projects that will show us, OK, this is a good idea to start working on district heating,” said (PLD, Interview 9, 2024) . The lack of such projects inhibits the potential for scaling up aquathermal energy systems in addition to impeding public acceptability. ”If we are not able to have some successful pilots in the near future, then we will not be able to scale up,” stressed (PF2, Interview 6, 2024), coordinator for the regional aquathermal energy initiative.

The sole noteworthy project at the moment is a little installation in Leeuwarden that provides heat for an office building. This is not enough, though, to show that aquathermal energy is feasible on a bigger scale. Although these projects are still in the development stage, the region has chosen five villages, including Terherne and Balk, as possible pilot regions. Since local governments and energy cooperatives are hesitant to engage in experimental technology, the lack of successful examples leads to a circle of hesitancy among stakeholders.

The situation is further complicated by the financial risks involved with these ventures. ”The municipalities are having cold feet setting up, entering and joining such heating companies” because they are afraid of losing money, according to (PLB, Interview 4, 2024). This emphasises how important it is to have a successful pilot project that can act as a template for other projects and show the viability and advantages of aquathermal energy systems. The region runs the risk of slipping behind in its energy transition objectives without such a project, which are becoming more pressing as the deadline for reducing reliance on fossil fuels draws near.

According to the interviews, a key component of strategic niche management in Friesland is the implementation of small-scale pilot projects. (PF2, Interview 6, 2024) clarified, ”We use small-scale pilots

to understand what works in practice and address technical challenges before expanding.” In a comparable vein, (PF1, Interview 5, 2024) stated, “Our learnings from this pilot project will guide how we approach similar projects in other villages.” The significance of iterative experimentation in identifying technological, operational, and social difficulties is emphasized by these remarks. Niche actors can improve their tactics and put themselves in a better position for scaling by viewing pilots as teaching opportunities.

The interviews emphasized the significance of drawing on international experiences to improve Friesland’s AE speciality. (MMD, Interview 12, 2024) stated that “Denmark’s experience with district heating has been a useful model for developing AE systems in Friesland.” (MKB, Interview 13, 2024) continued, “Sharing knowledge across borders helps us adapt solutions to local contexts.” These findings highlight the importance of cross-border collaboration, in which proven solutions from other countries are customized to meet local constraints, hence accelerating the development and scaling of AE technologies.

Friesland utilizes small-scale pilot projects to understand what works in practice and to address technical challenges. The lessons from these projects guide similar projects in other villages. There is a recognition that operational experience is lacking in the Netherlands and that expertise from other countries like Denmark is needed. Additionally, there is an acknowledgment that the current national framework for district heating is based on large, commercially owned networks and may not be appropriate for the smaller scale of Friesland’s rural areas as stated by (PF2, Interview 6, 2024) “that comes down to the national framework and how it’s being developed. Because our national framework for district heating and district heating law, which is under advisement right now. It’s based on all the district heating networks we have in the Netherlands right now. Which are all commercially owned and in big city areas. So it’s something totally different than the small scale village”. SNM promotes iterative experimentation as a way to improve tactics and prepare for scaling up. It encourages the application of global lessons to local contexts and helps to create standards for more regional rural areas. By viewing pilots as learning opportunities, niche actors can improve their approaches and position themselves better for scaling. Denmark’s district heating systems, developed since the oil crisis in 1973, offer invaluable lessons in scaling, legal frameworks, and operational experience. Denmark’s approach shows how long-term planning and stable policies can be used to create a more successful energy transition (PLD, Interview 9, 2024). Furthermore, the study of projects in Sweden, Belgium and Denmark that will be presented in sub-question 4 emphasize the importance of integrating AE with other renewable sources for hybrid systems.

3. Network Formation and Collaboration

This aspect highlights the development of strong networks among various actors. This can include workshops and talks with scholars, policymakers, businesses, and rural communities. These networks can speed innovation by encouraging cooperation and knowledge exchange, as well as remove technological or social acceptance barriers (Raven, 2005), (Hoppe et al., 2024).

Local governments, cooperatives, and other organisations improve collaboration through systematic networking and decision-making. (MFM, Interview 1, 2024) emphasised the significance of various stakeholder involvement: “The energy cooperative is formally the initiator, but the project involves social housing companies, recycling facilities, municipalities, and technical advisors.” These interrelated initiatives ensure that knowledge and resources are effectively shared, resulting in a more unified approach to AE development. The 12 energy cooperatives and other organisations in Friesland rely heavily on networking and regular meetings to enhance collaboration and decision-making. (CC2, Interview 7, 2024), who manages the community of practice for aquathermal energy, emphasises the importance of these connections, saying, “We arrange meetings with several parties involved, specifically meeting with the local initiatives and municipalities.” This systematic approach enables stakeholders to share expertise, solve practical problems, and learn from one another’s experiences, ultimately contributing to the region’s energy transition objectives.

To elaborate further on the significance of network building and collaboration in Friesland, cooperative activities are crucial for promoting innovation, pooling resources, and driving aquathermal energy

adoption. Stakeholders in Friesland collaborate with international partners, drawing on global expertise to improve local strategy. (PLD, Interview 9, 2024) stated, "Learning from similar projects in Denmark and Sweden has been invaluable in shaping our approach," and (PF2, Interview 6, 2024) added, "We've studied their district heating systems, which are much more advanced, to understand how we can adapt similar principles here in Friesland." This cross-national partnership not only provides access to proven solutions; but also assists Friesland in addressing its own difficulties by incorporating worldwide best practices into local AE projects.

Furthermore, educational institutions and public engagement programs are part of Friesland's collaborative networks, which go beyond technical and municipal players. Workshops and training sessions offer chances for capacity-building, giving participants the information and abilities they need to assist in AE implementation. "We've been conducting workshops and information sessions to educate stakeholders about the potential of aquathermal energy," said (PF1, Interview 5, 2024). Through these efforts, Friesland's AE speciality is kept flexible and progressive by fostering a culture of ongoing learning and innovation. The integration of local and international networks also allows Friesland to better manage regulatory and policy concerns. By learning from the experiences of regions with sophisticated AE systems, Friesland receives insight on how to negotiate regulatory barriers and advocate for favourable policies. (PLH, Interview 11, 2024) emphasised the need of integrating local initiatives with larger policy frameworks, stating that they are "connected with a lot of other projects such as in Waterwarmth and Energie Samen," emphasising the role of inter-project collaboration in developing cohesive policies.

Building robust local networks is crucial to the development of aquathermal energy (AE) in Friesland. According to (CC2, Interview 7, 2024), "We organize regular workshops and meetings to ensure all parties are aligned on goals and progress." According to (PLB, Interview 4, 2024), "The involvement of local communities through cooperatives is essential to gain trust and ensure project success." This highlights the importance of citizen involvement. These initiatives show that niche actors place a high value on continuing to interact with a variety of stakeholders, such as citizens, cooperatives, and municipalities. In addition to bringing stakeholders together, creating these networks promotes dedication and trust, both of which are critical for long-term success. (Biresselioglu et al., 2024)

Friesland is actively working on network building through collaborations among municipalities, cooperatives, private firms, and international partners. The province acts as a connector between different stakeholders, including water boards, municipalities, and civil organizations. International partnerships, particularly with Denmark and Sweden, provide access to proven solutions and help Friesland adapt these best practices to local AE projects. There are also initiatives like Missy Waterwarmth that bring together various stakeholders such as municipalities, technical experts and universities. While there's a focus on local and regional actors, critical stakeholders like national government entities and large energy providers are not as fully integrated into the network. This is a significant gap, as these stakeholders control important aspects of policy, funding, and infrastructure (PF2, Interview 6, 2024). SNM application can help by encouraging the inclusion of more diverse stakeholders, especially those at the national level, and integrating large energy providers. This would provide a more complete network capable of driving change. As stated by (PLD, Interview 9, 2024) Denmark's success in district heating is due to strong government support, both financially and through regulations. This highlights the critical need for national-level support to reduce investment risks.

To sum up, the use of SNM concepts in Friesland's AE niche emphasises how crucial stakeholder involvement, pilot projects, and iterative learning are to promoting creativity and scalability. Friesland has built a strong basis for AE growth by bringing together a variety of stakeholders, establishing common objectives, and utilising both domestic and foreign partnerships. Notwithstanding obstacles like financial limitations and legal restrictions, the region's dedication to community empowerment, consistent communication, and flexible approaches guarantees that AE projects could be scalable and long-lasting.

4.2.3 The Reality of SNM in Friesland's AE Development

Strategic Niche Management (SNM) identifies three critical stages for the effective development of new technologies such as aquathermal energy (AE): nurturing, shaping expectations, and learning. Nurturing

entails providing safe environments in which innovations can thrive through supportive legislation, funding, and stakeholder networks. Shaping expectations entails unifying views among many stakeholders in order to gain support, whereas learning entails iterative development through pilot projects and feedback loops. If SNM were used directly, one may expect these mechanisms to promote the growth of any emerging technology in any setting. However, reality in Friesland shows that this is not the case.

Friesland has a unique advantage in the form of energy cooperatives, which play an important role in developing AE projects. These cooperatives, as demonstrated by initiatives such as Warm Heeg, engage communities, match stakeholder expectations through educational outreach, and encourage learning from pilot projects. This should, in principle, be an excellent setting for SNM to function smoothly. Despite the inclusion of these SNM features, AE has not scaled as one would expect. For example, while stakeholders have a vision of reducing reliance on fossil fuels, the practical implementation of AE confronts major challenges. Nurturing AE entails coping with the region's distinct water circumstances; the salinity of Friesland's waters, as highlighted by PF2 in Interview 6, 2024, affects heat exchanger operations, demanding more specialised technology than normal SNM would indicate. This suggests that the geographical and environmental context greatly affects the simple use of SNM concepts.

Educational campaigns and community participation have been used to shape expectations in Friesland, but these efforts do not alone foster social acceptance of AE. Economic concerns, such as high installation costs (MOL, Interview 3, 2024), play an important role than SNM may suggest, calling into question the concept that expectation management alone can promote technology adoption. High installation costs and the necessity for significant upfront investment demonstrate that economic factors can outweigh community involvement-shaped expectations. The economic backdrop in Friesland, with its less wealthier rural areas (MOL, Interview 3, 2024), differs from more economically vigorous places, where financial obstacles may be less prohibitive, influencing the applicability of SNM's expectation-shaping.

Furthermore, while lessons from pilot initiatives such as Warm Heeg are clear, their applicability to larger-scale implementation is hampered by Friesland-specific economic, legislative, and infrastructural constraints. The need for subsidies, as highlighted by MKB in Interview 13, 2024, and the opposition from water authorities due to ecological concerns (PF2, Interview 6, 2024), demonstrate that the learning process in SNM must navigate complex local dynamics, which are more than just technological or procedural learning but also include negotiating with existing socioeconomic and environmental realities. The regulatory landscape and societal acceptance in Friesland do not necessarily coincide with the simplified SNM model, demonstrating that local sociopolitical settings can have a substantial impact on the success of SNM learning processes.

Thus, while SNM provides a useful framework for studying the evolution of niche inventions, its application is not universally effective due to the need to align with local conditions, economic structures, and existing socio-technical regimes. This complexity explains why simply adopting SNM principles does not guarantee success for all technologies in all situations; each context necessitates specific approaches that take into account particular problems in addition to SNM's theoretical principles. The inclusion of energy cooperatives may help, but they do not guarantee success because each region faces unique issues that do not fit neatly into SNM's theoretical model. For example, regions without such cooperative organisations or with differing environmental, economic, or social factors may find SNM ideas even less relevant. The framework's performance is dependent on its adaptability to local settings, which can vary greatly, showing why SNM, while useful, is not a one-size-fits-all solution for technology integration and scalability.

4.3 Learnings from other AE Un/Successful Projects

The study of aquathermal energy (AE) systems in Friesland offers an opportunity to learn useful lessons from other initiatives throughout the world. Understanding how AE systems have been established, grown, and modified in various contexts is essential for overcoming local barriers and leveraging best practices. This sub-question focuses on findings from three in-depth interviews with stakeholders involved in AE initiatives in Denmark, Belgium, and Sweden, as well as a detailed workshop that examined the projects' successes and challenges. The interviews focus on key factors impacting AE adoption, including stakeholder participation, policy frameworks, technological hurdles, and financial sustainability. The workshop provided an opportunity for sharing practical experiences, identifying hurdles, and exploring innovative solutions that have contributed to the success of AE projects worldwide.

Denmark, Belgium, and Sweden which are part of the the Interreg North Sea II WaterWarmth project were chosen in comparison with Friesland because :

- Denmark

Because of similar geographical characteristics, such as low-lying areas, Denmark's water conditions are similar to those of the Netherlands. Similar water management techniques are required for flood control and water quality because both nations have sizeable areas of land below or close to sea level. As seen by the necessity of dikes along around 1,800 km of coastline to defend against storm surges, Denmark's coastline, like that of the Netherlands, is extensive with low-lying sections susceptible to flooding (Change, 2020). As members of the EU with responsibilities under the European Water Framework Directive (WFD), Denmark and the Netherlands share a commitment to sustainability and environmental preservation from a legislative standpoint. However, the Dutch model, where provinces and water boards have different functions, may not be the same as Denmark's approach to local governance in energy policy, where municipalities play a major part in project guarantees. Although the general EU laws offer a common foundation for policy learning and adaptation, this comparison shows how local governance systems might affect the feasibility of AE projects. (MMD, Interview 12, 2024)

- Belgium

Low-lying areas are among the geographical characteristics that Belgium and the Netherlands share, especially in areas like Flanders. Water management is essential in the Low Countries, which include Belgium, because of its low-lying plains and coastal areas. Although information of water conditions for AE aren't stated explicitly, the common topography suggests similar conditions. This is shown in the enormous network of rivers and the requirement for flood protection similar to the Dutch system (Britannica, 1998). Similar to the Netherlands, Belgium enjoys regulatory advantages from EU energy transition project money, which can support AE initiatives. Given their dense populations and industrial histories, Belgium and the Netherlands have somewhat similar regulatory environments with regard to environmental regulation, particularly in areas like Flanders. The federal structure of Belgium, however, may result in regional differences in the way policies are implemented, which may provide information about how various levels of governance impact the development of AE projects. An example of how financial and regulatory support might be organized in Friesland is the integration of AE with urban planning, which was aided by subsidies from European legislation. (MKB, Interview 13, 2024)

- Sweden

Sweden has water sources that are used for energy, even if it does not share the same low-lying features as the Netherlands. This comparison is not so much about direct geographical resemblance in height as it is about the larger European context where water management for energy purposes is taken into consideration. A distinct but pertinent viewpoint on AE water conditions is offered by Sweden's experience with managing water supplies in colder climes, including problems like ice formation (The New York Times, 2017). Though it currently functions inside the EU framework, much like the Netherlands, Sweden's regulatory environment for AE isn't as proactive as it was during its oil transition phase. Given that both nations must strike a balance between environmental preservation and energy innovation, Friesland may learn a lot from Sweden's approach to environmental permits and the role that towns play in project approval. A lesson on the significance of national-level support can be learned from Sweden's lack of state-level promotion of AE in comparison to possible Dutch initiatives (SSL, Interview 14, 2024)

This section tackles the fourth sub-research question:

What can we learn from other pilot and existing aquathermal energy projects in the world?

4.3.1 1- Stakeholder Engagement and Collaboration

Successful AE initiatives emphasise the value of stakeholder collaboration, which entails aligning various groups around common aims. Major contributors in Belgium's Buda Island initiative included municipalities, educational institutions, and healthcare facilities. (MKB, Interview 13, 2024) described the alignment as follows: "The city of Kortrijk owns many buildings on the island, while the healthcare facility is another major stakeholder. Together, they cover 50% of the heat demand, creating a feasible business case to start". This collaborative model demonstrates the importance of involving key heat consumers early on to provide a solid foundation for project implementation.

Denmark emphasises the importance of local energy communities. (MMD, Interview 12, 2024) added: "We've seen promising outcomes where energy communities transform projects into 'Yes, in my backyard' instead of resistance". This demonstrates how grass roots support can diminish resistance, resulting in a favourable environment for AE adoption. Friesland also has similar initiatives to develop collaborative networks between municipalities, residents, and private businesses.

Effective AE project management requires experience and knowledge exchange. (MMD, Interview 12, 2024) emphasises the necessity of having knowledge of district heating systems and community energy initiatives. In order to collect information on the financial feasibility and environmental effects of current pilot projects, Friesland should look to learn from them both domestically and abroad. Friesland can create a strong case for AE systems that appeals to the public and legislators by carrying out environmental assessments and feasibility studies.

Building a favourable image of AE is crucial, even though public resistance to it might not be as strong as it is for wind energy projects. (MMD, Interview 12, 2024) points out that AE projects can succeed or fail based on public awareness and support. Consequently, Friesland ought to fund community education and outreach initiatives that emphasise the advantages of AE, namely its capacity to lower carbon emissions and dependency on fossil fuels. Public trust and ownership of AE projects can also be increased by involving local stakeholders in the planning process.

4.3.2 2-Policy Frameworks and Regulatory Support

Regulatory contexts have a considerable impact on AE adoption. Denmark is facing hindrance as a result of its stringent policies. (MMD, Interview 12, 2024) clarified "If municipalities cannot provide guarantees, citizens must secure loans independently, often at higher interest rates, which can destroy a project's viability". The significance of creating a solid and transparent legislative environment is among the main lessons learnt. According to (MMD, Interview 12, 2024), a Danish climate specialist, as seen by the Middelfart project, which was delayed because of ambiguous laws, legislative uncertainty can seriously hinder project development.

Sweden has a comparable regulatory gap, with a lack of proactive government support of AE. (SSL, Interview 14, 2024) stated: "Municipalities play a strong role in permitting, but the state is not proactive in promoting AE like it was during the oil transition in the 1970s".

Belgium provides a more encouraging framework by obtaining subsidies through European energy transition policies. According to (MKB, Interview 13, 2024), "European legislation on energy transition provides subsidies, which are crucial for making AE projects viable in existing neighbourhoods".

Friesland should argue for regular financial and regulatory alignment by taking a cue from Belgium's integration with European frameworks. For Friesland, this entails giving top priority to the development of clear regulations that address environmental factors pertaining to water temperature and quality while simultaneously supporting AE projects.

4.3.3 3- Technical Challenges and Innovations

AE projects frequently face technical obstacles such as infrastructural constraints and environmental regulations. Environmental regulations in Denmark frequently make sites unavailable. "Many lakes and rivers are protected under environmental laws, making it difficult to secure permits for AE installations" (MMD, Interview 12, 2024) noted. Ice formation is one of the added difficulties brought on by Sweden's climate. "Ice formation can lift coils from the bottom of water bodies, posing challenges for stability" according to

(SSL, Interview 14, 2024) .

In spite of these obstacles, creative solutions have surfaced. Reliability is ensured by Belgium's hybrid system, which blends geothermal and AE energy. "Our system integrates AE for 85-90% of the load, with geothermal and other sources as backup" (MKB, Interview 13, 2024) explained. By addressing seasonal unpredictability and enhancing energy resilience, these hybrid approaches can provide Friesland a model to follow.

4.3.4 4- Financial Viability and Economic Models

One of the most important factors influencing AE success is still economic viability. The financial difficulties of expanding AE are reflected in Belgium's reliance on subsidies. (MKB, Interview 13, 2024) said, "Without tax changes on gas and electricity, AE projects require subsidies to be financially feasible". The issue of municipal guarantees in Denmark introduces another level of sophistication. (MMD, Interview 12, 2024) underlined that "If guarantees are removed, project financing becomes nearly impossible". Alternative financing schemes, such joint ventures with private investors or pension funds, can offer answers. To lessen its reliance on subsidies and develop sustainable economic models, Friesland could investigate such tactics.

4.3.5 5- Public Awareness and Acceptance

Adoption of AE requires promoting acceptability and increasing awareness. The rise of AE in Sweden is constrained by its limited visibility among private companies. According to (SSL, Interview 14, 2024) , "Private companies often recommend geothermal or air-source heat pumps, with AE only considered in specific cases". An organised approach to community engagement has worked well in Belgium. Before concentrating exclusively on AE, (MKB, Interview 13, 2024) explained their approach: "We want to first work together with inhabitants to get a more positive attitude towards a climate-proof future before focusing specifically on AE" Public education initiatives in Friesland are consistent with these universal teachings. As part of their proactive efforts to educate the public, (PLH, Interview 11, 2024) revealed, "They have had an education campaign for 6 weeks, delivering brochures to every household,"

4.3.6 6- Lessons from Pilots and Existing Projects

Pilot projects are very useful for determining viability and improving strategies. Denmark's emphasis on small-scale pilots emphasises how crucial comprehensive feasibility studies are. "A bulletproof feasibility study is essential for securing financing and ensuring project success". (MMD, Interview 12, 2024) said. In a similar vein, the Buda Island project in Belgium aims to achieve both technological and financial feasibility by coordinating AE systems with urban planning.

Long-term insights can be gained from Sweden's legacy projects. "We've been tracing retired professionals from older projects to understand how they navigated permitting and technical challenges" (SSL, Interview 14, 2024) stated. These historical viewpoints can direct current initiatives and assist stakeholders in foreseeing possible obstacles.

There are many lessons to be learnt from the establishment and expansion of aquathermal energy plants from the experiences of Denmark, Belgium, and Sweden. These teachings stress the value of cooperation, encouraging regulation, technological advancement, long-term financial viability, and public involvement. Friesland may overcome its obstacles, create a strong AE niche, and support the larger global energy transformation by combining these lessons with its own environment.

4.4 Summary of Interviews' Findings

- Common views

According to the findings, there is broad consensus among interested parties about the costs associated with developing aquathermal energy (AE) niches. The high expenses were mentioned by every interviewee as a significant barrier. According to (WWB, Interview 10, 2024), "The amount of money people need to pay to get connected, sometimes €20,000 or €25,000, is a major deterrent" (WWB, Interview 10, 2024). "There's no escaping the reality that the costs of these systems remain high," (PF2, Interview 6, 2024) said, echoing this sentiment. "We see people dropping out of interest due to upfront costs" (PF1, Interview 5, 2024) was another point. According to (PLB, Interview 4, 2024) , "Crowdfunding campaigns have proven useful to involve local residents, but larger subsidies are still

critical" (PLB, Interview 4, 2024). (MFM, Interview 1, 2024) stated that "the cost burden discourages even technically feasible projects", and PLD said "These costs will remain a barrier unless financing mechanisms evolve" (PLD, Interview 9, 2024). And according to (PLH, Interview 11, 2024), "The costs are indeed high, but subsidies help to mitigate the burden". Externally, (MKB, Interview 13, 2024) from Sweden agreed, stating that "AE systems are not affordable for most people unless subsidised", while (MMD, Interview 12, 2024) from Denmark further highlighted that "Funding models play a crucial role in addressing high upfront costs". It is widely acknowledged by all interviewees that the cost barrier to AE adoption exists. According to the interviewees, the biggest obstacle to growing AE systems is still this issue, even though subsidies and other financing sources provide some relief, underscoring the need for subsidies, innovative financing models, and municipal guarantees.

Community involvement and public awareness become another widely accepted priority. "These projects won't succeed in the long run without trust-building," (PF2, Interview 6, 2024) said, while (PF1, Interview 5, 2024) explained their strategy by stating, "We hold open-house events to show people how these systems work". According to (PLB, Interview 4, 2024), "Community awareness has to precede implementation for buy-in", while (MFM, Interview 1, 2024) said, "It's not just about technical success but public understanding". "In Heeg, we emphasise community ownership to build trust and acceptance," said (PLH, Interview 11, 2024) from Friesland, and "Collaborating with housing associations ensures residents are informed about energy benefits" ((MKB, Interview 13, 2024). All interviewees concur that building community trust via openness and education is essential to the adoption of AE.

Collaboration among stakeholders was also consistently stressed. Additionally, (PF2, Interview 6, 2024) emphasised that "We need more structured collaboration frameworks between municipalities and local initiatives". According to PF1, "without involving housing corporations, technical experts, and the public, there is no success" (PF1, Interview 5, 2024). (MFM, Interview 1, 2024) noted, "We can't succeed without heat companies, municipalities, and contractors working together", and (PLB, Interview 4, 2024) added, "Collaboration is key, especially when resources are limited". As (CC2, Interview 7, 2024) of Friesland pointed out, "We arrange meetings with several parties involved, specifically meeting with the local initiatives and municipalities" and "We work with private consultants and public entities to ensure projects stay on track", (PLD, Interview 9, 2024) emphasised that "Local collaboration strengthens technical and operational efficiency". Externally, (MKB, Interview 13, 2024) stated that "Collaboration with housing corporations and municipalities is essential for success" and (MMD, Interview 12, 2024) stated that "Bringing together diverse stakeholders is key to scaling these projects". Accordingly effective collaboration among municipalities, local initiatives, technical experts, and private entities is essential for AE scaling and operational success.

- Un-common views

There were also disagreements about the urgent need for insulation in homes. (MKB, Interview 13, 2024) concurred with (CC2, Interview 7, 2024)'s statement that "improving housing insulation is a foundational step for energy efficiency", adding that "Housing insulation ensures that AE systems operate effectively with minimal energy loss" (MKB, Interview 13, 2024). (PLB, Interview 4, 2024) agreed, stating that "Insulation reduces overall energy demand, making AE systems more viable". (WWB, Interview 10, 2024) disagreed, saying, "We need to focus on making AE systems operational first before worrying about insulation" (WWB, Interview 10, 2024). While insulation is widely regarded as a critical element for long-term energy efficiency, some stakeholders argue for prioritizing operationalizing AE systems to ensure immediate viability.

The viability of AE systems in colder climate was a topic of debate. "Even in colder regions, technical solutions have proven effective" (MKB, Interview 13, 2024) expressed optimism. "Seasonal variations in water temperature significantly affect system efficiency" was one of (MMD, Interview 12, 2024)'s worries. "We need to adapt AE systems to be viable year-round in colder climates" was an assessment from (MFM, Interview 1, 2024). Seasonal efficiency losses in colder climates are still an issue, despite successful adjustments in places like Sweden. To overcome these obstacles, creative technical solutions are required.

Another topic of discussion was the role of private businesses in the development of AE. "For assessments and expertise, especially for technical challenges," (CC1, Interview 2, 2024) said, "we frequently consult private firms". "Private companies are essential partners in scaling and providing innovative solutions" is another statement that (MMD, Interview 12, 2024) echoed. "Private companies are not as involved here; we rely more on public entities for oversight and implementation," (MKB, Interview 13, 2024) explained, highlighting a different strategy in Sweden. (MKB, Interview 13, 2024) also added "Private sector participation is mostly confined to technology provision, with little role in decision-making". The function of private businesses differs greatly by location. Sweden depends more on public organizations, which reflects different governance structures than Friesland and Denmark, which place more emphasis on private sector involvement for scalability and innovation.

Main Common Views	Main Un-common Views
1. High Costs as a Barrier: All interviewees agree that the high upfront costs of AE systems are a significant barrier to adoption (e.g., WWB, PF2, PF1, PLB, MFM, PLD, PLH, MKB, MMD).	1. Need for Insulation: While some argue insulation is crucial for energy efficiency (CC2, MKB, PLB), others prioritize operationalizing AE systems first (WWB).
2. Community Involvement and Awareness: Essential for the success of AE projects, with emphasis on trust-building and public education (PF2, PF1, PLB, MFM, PLH, MKB).	2. Viability in Colder Climates: Debate exists on the effectiveness of AE in colder climates, with some optimistic about technical solutions (MKB) and others concerned about efficiency losses (MMD, MFM).
3. Stakeholder Collaboration: Strong consensus on the need for collaboration among various stakeholders including municipalities, local initiatives, technical experts, and private entities for scaling and operational success (PF2, PF1, MFM, PLB, CC2, PLD, MKB, MMD).	3. Role of Private Businesses: Differences in the involvement of private sector; some areas rely heavily on private firms for innovation and scaling (CC1, MMD), while others prefer public oversight (MKB).
4. Subsidies and Financing: There is a common understanding that subsidies and innovative financing models are necessary to mitigate the cost burden of AE systems (PLB, PLH, MKB, MMD, PLD).	
5. Technical Feasibility: Despite cost concerns, there's agreement that AE systems are technically feasible and can contribute significantly to energy transition goals, provided the right conditions are met (PF2, MFM, WWB, CC1, MOL, PF1, PLD).	

Table 4: Summary of Main Common and Un-common Views from Interviews

5

DISCUSSION AND CONCLUSION

This section starts by presenting and answering sub-questions in order to address and answer the main research question, followed by an academic discussion, conclusion, research implication, research limitations and future outlook and recommendation.

5.1 Sub-questions

Here are paragraphs addressing each sub-question, demonstrating how each leads to the next and collectively contribute to the main research question:

1. Sub-Question 1:

What does the AE niche in Friesland look like?

Friesland's aquathermal energy (AE) niche is distinguished by its rising prominence in an area with abundant surface water resources. Due to its rural setting and low population density, Friesland has started initiatives like Warm Heeg, which are prime examples of community-driven strategies for energy sustainability. These projects integrate AE into larger sustainability programs by concentrating on using surface water for heating and cooling. However, the market is still relatively new, with the majority of installations being restricted to private residences or modest community initiatives. This scenario highlights the necessity for a shift to more sustainable options like AE which opens for the next question to investigate the existing heating system regime, which is primarily dependent on fossil fuels.

2. Sub-Question 2:

How to analyse Friesland's existing heating system regime in the context of MLP framework?

Using the Multi-Level Perspective (MLP) framework to analyse Friesland's heating system reveals a regime dominated by conventional fossil fuel systems, which are stable because of established infrastructure and financial interests. Changes in the landscape, such as the public's desire for sustainability and decarbonization goals, put pressure on this regime and open doors for technologies like AE. However, the lack of extensive district heating networks, high connection fees, the salinity of local water bodies and inadequate infrastructure, and reliance on subsidies all demonstrate the regime's resistance to change which hinders AE integration. Given that current regime provides both barriers and opportunities for such innovations, this analysis emphasizes the need to implement Strategic Niche Management concepts in order to support the expansion of AE.

3. Sub-Question 3:

How may SNM principles be applied to AE niche in Friesland and ultimately scaling AE?

Scaling AE in Friesland can be facilitated by applying Strategic Niche Management (SNM) methods, which emphasize learning processes, network creation, and expectation shaping. Community projects like energy cooperatives have already established distinct, common goals for the development of AE in the area. The cooperative efforts in pilot projects demonstrate the need of networking between municipalities, cooperatives, and technical specialists. Strategies for larger-scale implementations are informed by the lessons learned from these pilots, such as Heeg. However, the use of SNM in Friesland must take into account local characteristics such as high salt in water bodies and economic obstacles.

The lessons learnt from these pilots must be contextualised, taking into account the particular environmental and economic challenges. Moving from niche to broader acceptance necessitates not just scaling up but also strategically modifying techniques to local situations, including advances in technology to manage saline environments and financing models to overcome high initial expenses. By laying the groundwork for learning from other international AE projects, these concepts aid in comprehending how to move from a niche to wider acceptance.

4. Sub-Question 4:

What can we learn from other pilot and existing aquathermal energy projects in the world?

The development of Friesland's AE niche can benefit from insights of global AE projects. Projects in Sweden, Denmark, and Belgium demonstrate how valuable it is to integrate AE with other renewable sources for hybrid systems, have clear legal frameworks, and engage stakeholders in a strong manner. These areas have demonstrated that financial assistance measures like as subsidies or creative funding models, along with education and open communication, can help overcome economic constraints and public mistrust. In order to address the main research question on the factors that influence AE niche development, these lessons can be applicable to Friesland and offer methods for scaling AE by modifying international best practices to local settings.

5.2 The Main Research Question

The following part addresses the main research question which is a combination of all the results and analysis of the previous four sub-research questions.

What factors influence surface water aquathermal energy (AE) niche development in rural Friesland region?

This researchers has found the following factors to have the most influence on the development of Surface Water Aquathermal Energy (AE) in rural Friesland, these include technological, financial & economic, environmental, social elements, and governmental regulations. One of the most significant technological factors is the quality and temperature of the water bodies used in aquathermal systems. According to (PF2, Interview 6, 2024) , "the larger part of Friesland is salt water," complicating the deployment of heat exchangers. Furthermore, the ecological impact of extracting heat from water bodies is a major problem, since it might harm local aquatic life and water quality. Friesland's water management procedures, which include a sophisticated pumping system to regulate water levels, limit the practicality of aquathermal systems.

The financial viability of aquathermal energy systems is an important consideration. MOL pointed out that the initial installation costs are significant, making widespread adoption difficult. Individual homeowners may lack the requisite cash to invest in such systems, making the cost burden even more evident. The economic landscape is also impacted by variable energy prices; as stated by different stakeholders, the price of gas and electricity substantially impacts the appeal of aquathermal energy as an alternative heating source.

Government laws and regulations can help or hinder the development of aquathermal energy. On the one hand, municipal governments are making a significant effort to transition away from natural gas, as emphasised by MOL, who declared, "In 2050, there will be no natural gas in the Netherlands anymore". However, the legislative framework could create barriers, notably in terms of environmental evaluations and the precautionary principle that governs water quality management. (PF2, Interview 6, 2024) observed that water authorities are often opposed to large-scale systems due to concerns about their ecological impact, which can cause delays in project clearances.

Social acceptance and stakeholder engagement are also critical for the effective deployment of aquathermal energy systems. Involving local communities, energy cooperatives, and municipalities in decision-making processes develops a collaborative environment, which can result in more effective project outcomes. (CC2, Interview 7, 2024) emphasised the necessity of stakeholder networking, adding, "Everybody is trying to learn and looking for confirmation of the next step". The 12 energy cooperatives in Friesland have regular meetings and knowledge-sharing sessions to encourage the exchange of best practices and lessons learnt from previous initiatives.

Furthermore, incorporating aquathermal systems into existing heating infrastructures presents additional obstacles. Many buildings in Friesland are old and poorly insulated, demanding higher temperature outputs from heating units. As (PF2, Interview 6, 2024) stated, switching from gas boilers to heat pumps requires careful examination of existing heating systems to ensure compatibility and efficiency.

To summarise, Table 5 combine all the discussed factors indicating that the growth of Surface Water Aquathermal Energy in rural Friesland is driven by a complex interplay of technological, economic, environmental, and social factors. Addressing these problems necessitates a diverse approach that includes improving water management techniques, strengthening financial support mechanisms, encouraging stakeholder collaboration, and adjusting legislative frameworks to promote the growth of aquathermal energy systems. As the region works towards its energy transition goals, the successful implementation of aquathermal energy will rely on the collaborative efforts of all stakeholders.

Findings	Description
Technological suitability	The effectiveness of AE depends on the quality and temperature of local water bodies, compatibility with existing infrastructure and high salinity posing unique challenges for heat exchanger operations .
Economic barriers	High initial investment and connection costs, coupled with reliance on subsidies, pose challenges to scaling AE.
Environmental concerns	Potential ecological impacts on water bodies and management practices are significant considerations.
Social acceptance	Community education, involvement, and trust are vital for public acceptance of AE systems.
Governmental influence	The regulatory and policy landscape can either facilitate or hinder AE development through support, clarity, and adaptability.

Table 5: Factors influencing AE Niche Development in Friesland

5.3 Academic Discussion

This section relates the findings in this chapter to the literature presented in both Chapter 1 and Chapter 2 in order to also validate and cross check the findings.

Chapter 4 uses the Multi-Level Perspective (MLP) framework to examine the Friesland heating system regime, demonstrating how external influences from landscape factors such as decarbonisation ambitions affect the current regime. The findings are consistent with Chapter 2 theory of MLP, in which landscape-level changes offer possibilities for niche innovations. For example, Friesland’s aquathermal energy (AE) efforts benefit from worldwide trends that favour renewable energy ”In 2050, there will be no natural gas in the Netherlands any more” (MOL, Interview 3, 2024), This remark indicates a landscape shift that challenges the current regime of fossil fuel-based heating, presenting potential for AE. Which is compatible with Geels’ hypothesis of regime destabilisation caused by external pressures (Geels, 2002); (Geels & Schot, 2007); (Smith et al., 2005)). However, the regime’s opposition, marked by economic lock-ins and regulatory inertia, is also visible: ”The amount of money people need to pay to get connected, sometimes €20,000 or €25,000, is a major deterrent” (WWB, Interview 10, 2024). This is consistent with the findings of Geels and Schot, who suggest that regime stability could hinder the adoption of new technologies due to vested interests and established infrastructures (Geels & Schot, 2007), which also resonates with (Truffer & Coenen, 2012) observations on path dependencies.

According to the research, landscape changes alone can destabilise the regime enough for niche innovations to emerge (Geels, 2011) . However, the research findings show that in Friesland, the regime’s resistance may

be greater than expected. "The water boards are a bit hesitant when it comes to large-scale systems" (CC2, Interview 7, 2024). This hesitation suggests that even with supporting landscape forces, the entrenched regime can still pose major limitations, implying the need for a more comprehensive understanding of regime dynamics (Geels, 2011).

Chapter 4's research of Friesland's AE niche demonstrates the SNM principles covered in Chapter 2: voicing expectations, network development, and learning processes. Pilot initiatives in Heeg and Leeuwarden highlight the importance of experimentation and stakeholder participation in driving innovation. Chapter 4 builds on SNM's theoretical application by highlighting iterative learning and public participation as essential success elements (Raven, 2005); (Kamp & Vanheule, 2015); (Van Eijck & Romijn, 2009). The findings demonstrate these aspects in community-driven projects such as Warm Heeg. "We have started a crowdfunding campaign to involve local residents in funding the project" (PLB, Interview 4, 2024). This supports the SNM principle of network formation, in which local activities reinforce the niche by involving citizens. This is consistent with (Kemp et al., 1998) findings, which emphasise the role of stakeholder networks in niche development. In addition, this grass roots approach to funding and community involvement is consistent with the findings of (Seyfang et al., 2013), who contend that local energy projects can greatly help sustainability transitions by creating community empowerment. It adds a practical dimension to (Kemp et al., 1998) theoretical observations about the role of networks in niche creation.

In terms of financing, Friesland's reliance on novel financial models such as crowdfunding and local startup banks contributes to (Mazzucato & Semieniuk, 2018) discussion of the importance of specialised financial mechanisms for renewable energy. "In Gelderland, the province has made a sort of startup bank... set up to stimulate initiatives for the heat transition" (CC2, Interview 7, 2024). This local financing innovation adds weight to (Polzin et al., 2015) broader argument on the significance of public finance in promoting green technology in their early phases of development.

The research in Chapter 1 highlights how important legal frameworks are to the effective deployment of renewable energy technologies, especially aquathermal energy (AE) systems. This idea is supported by the interview results, particularly in regard to legislative ambiguity. (MMD, Interview 12, 2024), for example, noted that "the lack of clear legislative guidance led to the abandonment of projects," which is consistent with the literature's claim that innovation in energy systems requires a stable legislative context. This is in line with (Falkner, 2016) research, which highlights the significance of well-defined policies in accomplishing climate objectives. The literature's demand for comprehensive governance structures to enable AE development is further supported by (MKB, Interview 13, 2024)'s observation that coordinated rules are necessary.

The interviews additionally highlighted the significance of public acceptance and involvement, an issue that has been extensively covered in the literature as a necessary condition for effective technological adoption. "If people dislike AE initiatives, it can create significant challenges," (MMD, Interview 12, 2024) said, repeating the literature's focus on the necessity of implementing efficient communication techniques to promote public comprehension. This is consistent with research by (Goossens et al., 2021), which shows that public opinion has a big impact on how feasible renewable energy projects are. Furthermore, (Falkner, 2016) emphasizes the value of community involvement in energy transitions and proposes that participatory approaches that include stakeholders in decision-making processes might improve public acceptance. This is consistent with (Devine-Wright, 2007) concept of 'energy citizenship', which holds that public participation is critical to the acceptance of new technologies. Furthermore, (Walker & Devine-Wright, 2008) argue that community engagement can be just as important for acceptability as economic factors.

The theoretical frameworks of Multi-Level Perspective (MLP) and Strategic Niche Management (SNM) were presented in Chapter 3 as analytical instruments for comprehending technological shifts. The results of the interviews provide credence to the use of these frameworks, especially when it comes to stakeholder networking and cooperation. Building alliances is essential, according to PLB, who said that "networking and lobbying among stakeholders can help streamline the process." This cooperative strategy is mirrored in the literature, which contends that various players must be involved for transitions to be effective in order to foster an innovative atmosphere. (Geels, 2002) claims that because multi-actor networks promote resource sharing and information exchange, they are crucial for the spread of innovative technologies.

The interviews also demonstrated the value of information exchange and expertise in AE project management. According to (MMD, Interview 12, 2024), who cited his experience with community energy initiatives, "successful implementation requires expertise and collaboration among various actors involved." This result is consistent with the literature's focus on using lessons learned from previous endeavours to guide current and future ones. Sharing best practices can increase the efficiency of energy projects, according to (Kaphengst & Velten, 2014), who emphasize the value of knowledge exchange in overcoming implementation obstacles. Furthermore, (Orr, 2003) examines how social networks contribute to the spread of innovations, highlighting how stakeholders' information sharing might hasten the acceptance of new technology.

Participants voiced concerns over the high upfront costs of AE systems, and the findings also covered economic models and financial sustainability. According to (WWB, Interview 10, 2024), "the amount of money required to connect to the system can be a major deterrent for potential users," which is consistent with the literature's finding that financial barriers are a significant obstacle to the expansion of AE technologies. (van de Witte, 2023), who highlights the necessity of customized funding approaches to enable rural energy transformations, is reflected in this. (Mazzucato & Semieniuk, 2018) also contend that creative financing strategies, like public-private partnerships and community funding, can reduce financial risks and increase the appeal of renewable energy projects.

The participants also emphasized the importance of outreach and education initiatives in promoting public acceptance and understanding of AE systems. "Workshops and public awareness programs inform communities about AE benefits," according to PLH, which is consistent with the literature's focus on the necessity of efficient communication techniques to engage the public. This is in line with research by (Falkner, 2016), who emphasized the value of community engagement in the shift to sustainable energy sources. Additionally, (Wüstenhagen et al., 2007) point out that educational programs that make clear the advantages and features of renewable energy technology can greatly increase public acceptability. The interviews show that educational campaigns and transparency tools are important: "They have had an education campaign for 6 weeks, delivering brochures to people, each household" (PLH, Interview 11, 2024). This shows that in rural areas, understanding and trust are critical, which supports (Van der Schoor & Scholtens, 2015) discussion of the importance of community ownership in energy initiatives. Thus, the findings challenge the concept that economic incentives alone drive adoption, instead emphasising the significance of community education and engagement. Such as (Gross, 2007) who argues that economic incentives, such as direct financial benefits or cost reductions for local residents, have a greater impact on public support for renewable energy projects than educational efforts.

Technological adjustments are also in emphasis, notably with AE's performance in colder areas. "Even in colder regions, technical solutions have proven effective" (MKB, Interview 13, 2024). This discovery offers a fresh dimension to (Levidow & Papaioannou, 2013) work on customising technology to local demands, indicating that future study should address the adaptability of energy systems in various climatic situations to ensure their viability and adoption. This questions and extends on (Sovacool & Hess, 2017) work on technology in varied contexts, emphasising the importance of localised solutions, as argued by (Stirling, 2008) in his study of technological variety. Moreover, technological compatibility and infrastructure readiness are also significant factors influencing the adoption of AE systems. PF2 (Interview 6, 2024) pointed out that "switching from gas boilers to heat pumps requires careful examination of existing heating systems to ensure compatibility and efficiency." This concern is supported by (Kaphengst & Velten, 2014), who argue that addressing infrastructural barriers is essential for the successful integration of new technologies into existing systems.

This study also empathises the SNM framework's limitations presented in Chapter 2. Such as the straightforward application of Strategic Niche Management (SNM) by demonstrating that (Kemp et al., 1998) principles of nurturing, shaping expectations, and learning do not always result in the successful scaling of aquathermal energy (AE) in Friesland. While the establishment of energy cooperatives is consistent with SNM's nurturing component, environmental difficulties such as water salinity necessitate more than supportive policies, implying a need for technological adaptation that was not prominently emphasised in early SNM literature (Geels & Schot, 2007). Economic constraints complicate the moulding of expectations through community participation, implying that SNM may have underestimated the impact of economic variables in technology adoption, a topic that (Wüstenhagen et al., 2007) research has emphasised. Furthermore, the learning

from pilot projects is limited in its larger application due to local economic, regulatory, and infrastructural constraints, contradicting the direct scalability expected in classic SNM texts (Raven, 2005). This contrasts with (Berkhout et al., 2010) more nuanced perspectives, which emphasise that learning must be context-specific, underlining that while SNM provides a good framework, its application requires extensive adaption to local socio-technical factors in order to be effective. While SNM provides a solid theoretical framework for understanding how niche technologies like AE emerge, the Friesland case demonstrates that its deployment necessitates extensive customisation to local settings. The ideas of nurturing, shaping expectations, and learning remain valid, but they must be used with an understanding of the economic, environmental, and sociopolitical factors that can either accelerate or hinder the transition process. This suggests that future SNM research should concentrate on the interaction of these processes with the unique conditions of each niche habitat in order to improve the framework's practical utility.

The growth of surface water aquathermal energy (AE) in Friesland is a reflection of the larger energy shift, demonstrating both the benefits and problems of embracing innovative renewable technology. A thorough understanding of the elements impacting AE development in rural Friesland arises from an examination of the region's AE niche, existing heating system regime, application of Strategic Niche Management (SNM) concepts, and learning from global pilot projects.

Friesland's AE niche is a collaborative, community-driven program that is closely rooted in local sustainability objectives. It is distinguished by strong relationships among municipalities, cooperatives, technical consultants, and foreign collaborators. Local initiatives, such as Warm Heeg's village vision, demonstrate how grassroots efforts may incorporate AE projects into larger energy transition strategies, indicating how community-led frameworks promote inclusivity and long-term commitment. Despite its strengths, Friesland's AE sector is still developing, with few large-scale installations. The majority of current projects are limited to individual housing, with one notable exception: a small installation in Leeuwarden that provides heat to an office building. Nonetheless, progress is being made. Heeg has started excavation work for its AE project, which is a crucial step forward. This demonstrates an increasing momentum in the niche, which is supported by a common vision and proactive collaboration.

Analysing Friesland's current heating system regime using the Multi-Level Perspective (MLP) framework exposes contradictions between traditional practices and new sustainable technologies. The regime's reliance on fossil-fuel-based systems creates considerable economic, technological, and regulatory barriers to AE adoption. High initial prices hinder potential users. Infrastructure constraints, especially in older cities, complicate the integration of AE systems, as that in older city centres, the infrastructure is not ideal to lay all the pipe works because there are historic buildings and narrow streets. In addition to the water salinity which poses a corrosion complication as well requiring a specific heat exchangers which in accordance raises the cost. However, landscape forces, such as global decarbonisation targets and societal needs for long-term solutions, are driving change. Emphasizing the importance of aligning regional efforts with greater sustainability goals in order to scale aquathermal energy which will require collaboration across all levels—local, regional, and national—to align policies and funding. These challenges, along with niche innovations, are gradually destabilising the old heating regime, creating opportunities for AE integration.

Strategic Niche Management (SNM) concepts offer a road map for expanding AE in Friesland by emphasising innovation, stakeholder participation, and learning procedures. Pilot programs are critical for boosting confidence and improving technologies. Since testing the system before scaling helps stakeholders understand both the feasibility and limitations. These trials address technical and economic issues, ensuring that large-scale implementations are feasible and efficient.

Stakeholder participation is another key component of SNM. Collaborations among municipalities, cooperatives, private firms, and foreign partners form a strong network that propels AE growth. The value of learning was emphasised from worldwide projects, stating, from similar projects in Denmark and Sweden which has been helping in current approaches. Local cooperatives enable communities to actively participate in the energy transition, creating a sense of ownership and trust.

Iterative learning procedures facilitate AE scaling by incorporating feedback from pilot initiatives and stakeholder workshops. Public education campaigns and resources such as pricing calculators improve transparency by addressing concerns about costs and practicality. The efforts were summarised for example with

the education campaign for 6 weeks, delivering brochures to people, each household, Such activities ensure that AE systems are both technically strong and socially acceptable.

Insights from worldwide AE projects can help Friesland build its niche. Countries such as Denmark and Sweden provide models for district heating systems that mix AE with other renewable energy sources. Their district heating systems were studied, which are much more advanced, to understand how to adapt similar principles in Friesland. These examples highlight the value of hybrid systems in handling issues such as seasonal fluctuations in water temperature. Additionally, multinational projects emphasise the importance of comparable legal frameworks and financial incentives. Subsidy instability has been a reoccurring concern in Friesland such as instability of the subsidies and the rules change all the time. Learning from places with stable policy environments can help Friesland advocate for rules that encourage long-term planning and investment.

5.4 Conclusion

In conclusion, this study addressed a substantial knowledge gap in academic discourse by focusing on the governance and scaling of aquathermal energy (AE) systems in rural settings, specifically Friesland, utilising the Multi-Level Perspective (MLP) and Strategic Niche Management (SNM) frameworks. The problem statement emphasised a lack of understanding about the constraints and prospects for scaling AE in rural areas with abundant surface water supplies via MLP and SNM. To explore this, four sub-research questions were investigated: 1) What does the AE niche in Friesland look like? 2) How to analyse Friesland's existing heating system regime in the context of MLP framework? 3) How may SNM principles be applied to AE niche in Friesland and ultimately scaling AE? And 4) What can we learn from other pilot and existing aquathermal energy projects in the world?. These questions aimed to answer the main research question: What factors influence surface water aquathermal energy (AE) niche development in rural Friesland region? By addressing these questions, this study helps to close the knowledge gap and provides insights into the socio-technical dynamics of sustainable energy transitions in rural areas.

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The growth of Friesland’s aquathermal energy (AE) niche is influenced by economic, technical, regulatory, and social issues. High connection prices and considerable infrastructure investments pose significant economic barriers, making affordability a top priority for stakeholders. However, novel finance approaches, such as crowdfunding, provide promising possibilities. The crowdfunding strategy was presented to involve local residents in funding the project. Technological challenges, such as seasonal fluctuation and limitations in current infrastructure, necessitate innovative solutions such as hybrid systems and heat pumps. A potential solution could be using hybrid systems that combine aquathermal energy with other renewable sources for consistent performance. On the regulatory front, inconsistent and strict regulations frequently hinder growth. For example, AE storage in the ground can only be 20 degrees, higher than that is not allowed. Community participation is critical in overcoming these hurdles, developing trust, and cultivating long-term commitment among people. Transparent communication and public education programs are beneficial in clearing myths and boosting confidence in the technology. Such as transparent calculation like having a price calculator on the website. Finally, Friesland’s collaborative networks of local and international players contribute to AE development. The energy corporation is formally the initiator, but the project involves social housing companies, recycling facilities, municipalities, and technical advisors. These multiple aspects influence the growth and scalability of AE systems in Friesland, emphasising the complexities of moving to sustainable energy solutions.

The AE niche in Friesland shows the challenges and opportunities of moving to sustainable energy systems in a rural setting. Friesland has built a solid basis for AE development through collaboration, community-based initiatives, and iterative learning. Significant barriers, such as high costs, infrastructural limits, and regulatory restraints, must be overcome in order to attain scale. Friesland is well-positioned to become a pioneer in sustainable energy innovation if it continues to implement SNM principles, learn from global best practices, and cultivate inclusive stakeholder involvement. This path exemplifies the region’s commitment to sustainability while also providing significant lessons for other places looking to develop and grow renewable energy technologies.

5.5 Research Practical Implications

5.5.1 Management of Technology Practical Implications

The precise findings of the study and its thorough case analysis of Friesland's aquathermal energy (AE) are closely related to the research's practical implications. One important consequence is the chance for businesses that specialize in pre-insulated pipework and innovative heat exchange technologies to develop and localize their solutions. For instance, Chapter 4 emphasizes how investments in better materials and pipeline technology are required due to technological constraints such as heat loss during distribution. One also crucial topic addressed is the requirement for advanced heat pump systems that are both cost effective and capable of operating efficiently in areas with dispersed infrastructure. This directly motivates businesses to give R&D top priority in order to address these issues that could help in rural areas.

In Friesland, the high salinity of water bodies is a considerable difficulty for companies constructing aquathermal energy (AE) systems, reducing heat exchanger performance and longevity caused by corrosion. Companies must invest in R&D to develop or obtain corrosion-resistant materials, create heat exchanger designs that are suitable for saline conditions, and implement effective maintenance practices. Local adaptation, including testing, selling speciality items customised to saline circumstances can be critical. This scenario not only necessitates technological innovation, but it also creates a distinct market niche for businesses to become pioneers in adapting AE technology to specific environmental concerns.

Furthermore, organizations engaging in stakeholder management and consultation are provided with practical insights for strengthening collaboration among varied actors. Chapter 4 emphasizes iterative learning through pilot projects, demonstrating how enterprises can collaborate with local governments and cooperatives to co-create solutions. For example, the Heeg pilot demonstrates the effectiveness of community-driven approaches by demonstrating how consulting firms may promote trust-building processes through education campaigns and pricing transparency tools. This is consistent with the SNM principle of shaping expectations, which businesses can implement by developing accessible platforms for stakeholder involvement.

5.5.2 Broader Research Practical Implications

At the local level, the study outlines a strategy for cooperatives and small companies to play a leading role in AE adoption. As discussed in Chapter 4, Friesland's community-driven initiatives, such as in Leeuwarden demonstrate the practical advantages of shared ownership models. Local businesses can duplicate similar methods, using their proximity to communities to increase acceptance and involvement.

Moreover, the thesis emphasizes the economic opportunities for small and medium-sized firms (SMEs) in areas such as system maintenance, energy monitoring, and public awareness. For example, the study's concept of iterative learning emphasizes the importance of localized expertise in addressing technological issues, providing opportunity for SMEs to create specialist competencies. In the broader business landscape, foreign enterprises have a strong motivation to engage in knowledge exchange and collaboration with Friesland stakeholders. The research in Chapter 4 of cross-national cooperation, such as those with Belgium and Sweden, shows that such alliances can speed up technology transfer and AE system scaling. This is especially important for businesses trying to grow into locations with similar geographical and infrastructural characteristics.

Additionally, the findings highlight the need for alternative financing mechanisms to support AE projects. The interviews highlighted that high upfront fees are a big barrier for potential users. Companies can look into other finance structures, as community funding models or public-private partnerships, to reduce cost burdens and make AE systems more accessible. This method benefits individual users while also improving the general feasibility of AE projects in rural areas.

Finally, the study suggests that enterprises interested in AE should actively participate in policy advocacy to help establish a favourable regulatory environment. As mentioned before the interviews emphasized the necessity of clear legislative frameworks, Companies may assist create a more favourable environment for renewable energy technology by interacting with legislators and contributing to the formulation of rules that support its deployment.

5.6 Research Limitations

There are a number of restrictions on the study of surface water aquathermal energy (AE) niche development in the rural Friesland area that could limit how broadly and practically the results can be applied. First off, the study's scope is mostly limited to qualitative data from interviews and published works, which might not fully capture the range of quantitative measurements required for a thorough analysis. For example, the interviews might not fully capture the wider economic and environmental effects of AE systems in Friesland, even while they included insightful information about stakeholder attitudes and regulatory obstacles. Furthermore, bias may be introduced by depending too much on a small number of interviews because the opinions of key stakeholders might not be representative of the community as a whole or of other relevant individuals in the energy sector.

Additionally, the current level of aquathermal technology, which is still in its early stages in many areas, including Friesland, limits the investigation. Because of this early stage, it is difficult to draw firm conclusions regarding the potential success or scalability of AE systems due to the lack of empirical evidence on their long-term performance and viability. Furthermore, the AE market in Friesland is still niche, with few large-scale initiatives to offer a thorough grasp of long-term difficulties and achievements. The majority of instances are individual projects or small-scale implementations, such the heating system in an office building in Leeuwarden. It is difficult to extrapolate results on scalability and broad acceptance in the absence of significant operational projects.

The complexity and regional variations in the regulatory environment around AE may also restrict the generalisability of the lessons discovered in other pilot initiatives in Denmark, Belgium, and Sweden. Since local and regional regulations could not be in line with the requirements of AE development, the lack of a unified policy framework in Friesland makes matters more difficult and could cause disputes and delays in project execution. Finally, continual research and adaptation are necessary to stay up with changes in the energy landscape because of the dynamic nature of energy markets and technology breakthroughs, which means that the conclusions of this study may soon become outdated as new developments occur.

5.7 Future work and Recommendation

1. Future Research/Work Future research in the field of aquathermal energy (AE) in rural settings, particularly in places like Friesland, should attempt to solve many gaps and build on the findings of this study

- **Quantification of Environmental Impact:** Quantitative research is required to assess the long-term environmental impact of AE systems on local water bodies and ecosystems. This would entail extensive monitoring over numerous seasons to determine the full ecological impacts, resulting in a more comprehensive dataset to influence policy and public opinion.
- **SNM Framework Application**
Future SNM research should investigate how nurturing, shaping expectation, and learning processes interact with the unique economic, environmental, and sociopolitical characteristics of each niche setting in order to improve the framework's applicability. The research demonstrates that, while SNM provides excellent theoretical insights, its actual application necessitates extensive adaption to local situations.
- **Economic Viability Analysis:** Further study should focus on building complete economic models that examine the long-term cost-benefit of AE systems, such as lifespan costs, maintenance, and possible energy bill reductions for rural populations. This could include conducting longitudinal studies to track real-world performance and economic outcomes.
- **Technological Innovations:** It is critical to investigate technology breakthroughs that can overcome current limits, such as cold-weather efficiency or compatibility with existing infrastructure. Researchers could look into new heat exchanger materials or unique insulation approaches for rural structures.
- **Broader Stakeholder Involvement:** Expanding the scope of stakeholder research to include more varied voices, such as small companies, local environmental groups, and other under-represented

community people, would provide a more comprehensive picture of AE adoption and integration.

- **Cross-Region Comparative Studies:** Conducting comparison assessments with countries outside of Europe with similar rural characteristics but different socioeconomic situations could provide insights into how AE systems can be adapted globally, increasing the generalizability of the findings.

2. **Policy Recommendations Based on the findings of this study,** the following policy suggestions are proposed to support the growth and integration of AE systems in Friesland and similar rural areas.

- **Standardization of Regulatory Frameworks:** Policymakers should seek to create a consistent and supportive regulatory environment that facilitates the approval process for AE projects, addressing current gaps among municipalities or water authorities.
- **Financial Incentives and Support:** Introduce or improve subsidies, tax breaks, or novel financing structures, such as community investment funds or green bonds, for rural AE projects. This might include subsidies for experimental projects or low-interest loans for community heating networks.
- **Education and Outreach Programs:** Governments should sponsor and promote educational activities that raise public knowledge and understanding of AE. This includes community workshops, school initiatives, and information campaigns explaining the benefits and mechanics of AE systems.
- **Integration with Existing Infrastructure:** Policies could support the integration of AE into existing heating systems by providing incentives for renovating older buildings or developing district heating networks in rural regions, lowering the cost barrier to new installations.
- **Community and Local Governance Involvement:** Develop policies that enable local governments and energy cooperatives to lead AE programs by providing them with the legal framework and resources they require to manage and scale these initiatives. This could include recognizing community energy groups in policymaking or giving them decision-making autonomy on local energy projects.
- **Long-term Policy Stability:** Ensure policy consistency over time to reassure stakeholders on long-term investment in AE. This could entail establishing explicit, long-term goals for AE adoption within regional energy programs or national climate action plans.

REFERENCES

- Aquacom [Source of information on aquathermal energy initiatives in Friesland]. (2021).
- Aquathermie, N. (n.d.). Governance. <https://www.aquathermie.nl/governance/default.aspx>
- Bauwens, T., Gotchev, B., & Holstenkamp, L. (2016). What drives the development of community energy in europe? the case of wind power cooperatives. *Energy Research & Social Science*, 13, 136–147. <https://doi.org/10.1016/j.erss.2015.12.016>
- Berkhout, F., et al. (2010). Title of the article. *Journal Name*, Volume Number, StartPage–EndPage.
- Biresselioglu, M. E., Demir, M. H., Solak, B., Savas, Z. F., Kollmann, A., Kirchler, B., & Ozcureci, B. (2024). Empowering energy citizenship: Exploring dimensions and drivers in citizen engagement during the energy transition. *Energy Reports*, 11, 1894–1909.
- Bosselaar. (2024). Aquathermie: Je huis verwarmen met water uit de sloot. <https://www.omropfryslan.nl/nl/nieuws/16281654/aquathermie-je-huis-verwarmen-met-water-uit-de-sloot>
- Britannica. (1998). *Low countries — facts, map, & history*. Retrieved January 12, 2025, from <https://www.britannica.com/place/Low-Countries>
- Britannica. (2024). *Friesland*. <https://www.britannica.com/place/Friesland>
- Bryson, J. M. (2004). What to do when stakeholders matter: Stakeholder identification and analysis techniques. *Public management review*, 6(1), 21–53.
- Change, C. (2020). *Denmark - summary*. Retrieved January 12, 2025, from <https://climateknowledgeportal.worldbank.org/country/denmark>
- Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis*. sage.
- Cherp, A., Vinichenko, V., Jewell, J., Brutschin, E., & Sovacool, B. (2018). Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework. *Energy Research & Social Science*, 37, 175–190.
- de Nijs, S. S. (n.d.). Advancing niches through continuous shaping of socio-political realities.
- Deals, G. (2019). Deal tekst gd 229 aquathermie. <https://www.greendeals.nl/green-deals/green-deal-aquathermie>
- Deals, G. (2023). 1,9 miljoen voor fryske wetterwaarmte ambitie. <https://www.rondomvandaag.nl/drachten/natuur/33568/1-9-miljoen-voor-fryske-wetterwaarmte-ambitie>
- Delft, T. (2024). Msc management of technology. <https://www.tudelft.nl/onderwijs/opleidingen/masters/mot/msc-management-of-technology>
- Devine-Wright, P. (2007). Energy citizenship: Psychological aspects of evolution in sustainable energy technologies. In *Governing technology for sustainability* (pp. 63–86). Earthscan.
- Energietafel, F. (2022). Friese energietafel samenwerkingsdocument. <https://frieseeenergietafel.nl/files/fet-samenwerkingsdocument.pdf>
- Esrig. (2024). Esrig - energy and sustainability research institute groningen. <https://www.rug.nl/research/esrig/?lang=en>
- Essent. (2024). Ontdek ons bedrijf. <https://www.essent.nl/over-essent>
- Europe. (2024). *Population statistics, charts, map and location*. https://www.citypopulation.de/en/netherlands/admin/NL12_friesland/
- EZK. (2024). Developmentaid. <https://www.developmentaid.org/donors/view/179079/ministry-of-economic-affairs-and-climate-ministerie-van-economische-zaken-en-klimaat-ezk>
- Falkner, R. (2016). The paris agreement and the new logic of international climate politics. *International Affairs*, 92(5), 1107–1125.
- Fremouw, M. (2024). *Heating your home with lake water: The “magic” of aquathermal energy*. <https://www.tudelft.nl/en/architecture-and-the-built-environment/research/research-stories/heating-your-home-with-lake-water-the-magic-of-aquathermal-energy>
- Fryslan, W. (2022). Provincie fryslân. <https://www.fryslan.frl/wetterwaarmte>
- Fryslân, R. (2021). Regionale energie strategie 1.0 fryslân. https://frieseeenergietafel.nl/files/res-1.0_res-fryslan.nl_def_digitaal.pdf

- Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research policy*, 31(8-9), 1257–1274.
- Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research policy*, 33(6-7), 897–920.
- Geels, F. W. (2005). *Technological transitions and system innovations: A co-evolutionary and socio-technical analysis*. Edward Elgar Publishing.
- Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental innovation and societal transitions*, 1(1), 24–40.
- Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research policy*, 36(3), 399–417.
- Goossens, J., Hadházi, L., Iping, N., Lammers, N., & van der Sangen, N. (2021). Potential of aqua thermal energy in the utrecht heuvelrug: Working towards a climate-neutral future.
- Gross, C. (2007). Community perspectives of wind energy in australia: The application of a justice and community fairness framework to increase social acceptance. *Energy Policy*, 35(5), 2727–2736.
- Gürsan, C., de Gooyert, V., de Bruijne, M., & Raaijmakers, J. (2024). District heating with complexity: Anticipating unintended consequences in the transition towards a climate-neutral city in the netherlands. *Energy Research & Social Science*, 110, 103450.
- Hielscher, S., Seyfang, G., & Smith, A. (2013). Grassroots innovations in community energy: The role of intermediaries in niche development. *Global Environmental Change*, 23(5), 869–880. <https://doi.org/10.1016/j.gloenvcha.2013.02.008>
- Hoppe, T., Mohlakoana, N., Ness, B., & Brogaard, S. (2024). Wp 6 governance of collective energy systems: #1 framework and typology to analyse governance of current ae and other relevant heating systems.
- Janssen, M., & De Vries, L. (2020). The solar energy market in friesland: A competitive landscape. *Friesland Energy Journal*, 12, 45–58.
- Jason, L., & Glenwick, D. (2016). *Handbook of methodological approaches to community-based research: Qualitative, quantitative, and mixed methods*. Oxford university press.
- Kamp, L. M., & Vanheule, L. F. (2015). Review of the small wind turbine sector in kenya: Status and bottlenecks for growth. *Renewable and Sustainable Energy Reviews*, 49, 470–480.
- Kaphengst, T., & Velten, E. K. (2014). *Energy transition and behavioural change in rural areas-the role of energy cooperatives* (tech. rep.). WWWforEurope Working Paper.
- Kemp, R., Schot, J., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technology analysis & strategic management*, 10(2), 175–198.
- Klijnsma, X. (2018). *Local renewable energy initiatives in the natural gas-free energy transition in the netherlands: Obstacles, barriers and measures in niche development of local cooperative district heating by forerunner initiatives in the province of friesland* [Master's thesis, University of Twente].
- Lachman, D. A. (2013). A survey and review of approaches to study transitions. *Energy Policy*, 58, 269–276.
- Levidow, L., & Papaioannou, T. (2013). Title of the article. *Journal Name*, Volume Number, StartPage–EndPage.
- liander. (2024). Thuis en kleinzakelijk. <https://www.liander.nl/>
- Loorbach, D., & Verbong, G. (2012). Conclusion: Is governance of the energy transition a reality, an illusion or a necessity? In *Governing the energy transition* (pp. 317–335). Routledge.
- Mazzucato, M., & Semieniuk, G. (2018). Financing renewable energy: Who is financing what and why it matters. *Technological Forecasting and Social Change*, 127, 8–22.
- Meijerink. (2001, December). *The twente water covenant as an instrument for improving cooperation between municipalities, water boards and public utilities in the netherlands*. Retrieved January 12, 2025, from https://www.researchgate.net/publication/265073627_The_Twente_water_covenant_as_an_instrument_for_improving_cooperation_between_municipalities_water_boards_and_public_utilities_in_the_Netherlands
- Oerlemans. (2020). Aquathermie begint aan een inhaalrace. <https://www.h2owaternetwerk.nl/h2opremium/warmte-uit-water-de-grote-beloofte-van-de-energietransitie>
- Orr, G. (2003). Diffusion of innovations, by everett rogers (1995). Retrieved January, 21, 2005.
- Peters, I. K. (2022). No gas all local: Developing a renewable-based and decentralised energy system for the historic centre of amsterdam.

- Polzin, F., Migendt, M., Täube, F. A., & von Flotow, P. (2015). Public policy influence on renewable energy investments—a panel data study across oecd countries. *Energy Policy*, 80, 98–111.
- Popering-Verkerk, V. (2021). Warmte uit samenwerking — verkenning naar de governance van aquathermie. <https://www.aquathermie.nl/bibliotheek/handlerdownloadfiles.ashx?idnv=%202017931>
- Raven, R. (2005). Strategic niche management for biomass. *Eindhoven University, The Netherlands*.
- Schot, J., & Geels, F. W. (2013). Strategic niche management and sustainable innovation journeys: Theory, findings, research agenda, and policy. *The Dynamics of Sustainable Innovation Journeys*, 17–34.
- Schure. (2022). Systeemstudie fryslân (report commissioned by res fryslân). <https://friezeenergietafel.nl/files/%20rapport-systeemstudie-fryslan.pdf>
- Sea, I. N. (2023). Aquathermal energy find out if this free, sustainable and fossil free source fits your requirements. https://www.interregnorthsea.eu/sites/default/files/2024-04/1300_flyer_drieluik_digitaal.site_.pdf
- Seyfang, G., Park, J. J., & Smith, A. (2013). Community energy in the uk: The role of community ownership in achieving sustainable energy transitions. *Local Environment*, 18(1), 14–30. <https://doi.org/10.1080/13549839.2012.669380>
- Smith, A., Stirling, A., & Berkhout, F. (2005). The governance of sustainable socio-technical transitions. *Research policy*, 34(10), 1491–1510.
- Smith, A., Voß, J.-P., & Grin, J. (2010). Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. *Research policy*, 39(4), 435–448.
- Sovacool, B. K., & Hess, D. J. (2017). Ordering theories: Typologies and conceptual frameworks for sociotechnical change. *Social Studies of Science*, 47(5), 703–750.
- Stirling, A. (2008). "Opening up" and "closing down": Power, participation, and pluralism in the social appraisal of technology. *Science, Technology, & Human Values*, 33(2), 262–294.
- Strauss, A., & Corbin, J. (1998). Basics of qualitative research techniques.
- The New York Times. (2017). *The dutch have solutions to rising seas. the world is watching*. Retrieved January 12, 2025, from <https://www.nytimes.com/interactive/2017/06/15/world/europe/climate-change-rotterdam.html>
- Timmermans, S., & Tavory, I. (2012). Theory construction in qualitative research: From grounded theory to abductive analysis. *Sociological theory*, 30(3), 167–186.
- Truffer, B., & Coenen, L. (2012). Environmental innovation and sustainability transitions in regional studies. *Regional Studies*, 46(1), 1–21.
- van 't Westende T. (2021). *Thermal energy from surface waters: The thermal effects and underlying processes during thermal energy extraction from surface waters; a case study in the canals of amsterdam* (tech. rep.). TU Delft. <http://resolver.tudelft.nl/uuid:ee0d64d1-a496-4f6f-85ec-9006b44de501>
- van de Witte, M. (2023). The governance of surface water aquathermy in friesland.
- Van der Schoor, T., & Scholtens, B. (2015). Title of the article. *Journal Name*, Volume Number, StartPage–EndPage.
- van der Roest, E., Beernink, S., Hartog, N., van der Hoek, J. P., & Bloemendal, M. (2021). Towards sustainable heat supply with decentralized multi-energy systems by integration of subsurface seasonal heat storage. *Energies*, 14(23), 7958.
- Van Driel, H., & Schot, J. (2005). Radical innovation as a multilevel process: Introducing floating grain elevators in the port of rotterdam. *Technology and Culture*, 46(1), 51–76.
- Van Eijck, J., & Romijn, H. (2009). Prospects for jatropha biofuels in tanzania: An analysis with strategic niche management. In *Sectoral systems of innovation and production in developing countries*. Edward Elgar Publishing.
- Walker, G., & Devine-Wright, P. (2008). Community renewable energy: What should it mean? *Energy Policy*, 36(2), 497–500. <https://doi.org/10.1016/j.enpol.2007.10.019>
- Warmheeg. (2024). Logboek warm heeg. https://warmheeg.nl/wp-content/uploads/2022/11/221117_logboek0.1.2-1.pdf
- Waterschap. (2003). *Waterschap (nederland)*. Retrieved January 12, 2025, from [https://nl.wikipedia.org/wiki/Waterschap_\(Nederland\)](https://nl.wikipedia.org/wiki/Waterschap_(Nederland))
- Waterstaat, M. v. I. e. (2012). Roles and responsibilities of provincial government, municipal governments and water authorities. <https://www.government.nl/topics/environment/roles-and-responsibilities-of-provincial-government-municipal-governments-and-water-authorities>

- Waterstaat, M. v. I. e. (2023). Ministry of infrastructure and water management. <https://www.government.nl/ministries/ministry-of-infrastructure-and-water-management/organisation>
- WaterWarmth. (2022). Pilots. waterwarmth interreg north sea. <https://www.interregnorthsea.eu/waterwarmth/pilots>
- Wind energy development in friesland.* (2019) (Report on stakeholder dynamics in Friesland's wind energy sector). Friesland Energy Authority.
- Wüstenhagen, R., Wolsink, M., & Bürer, M. J. (2007). Social acceptance of renewable energy innovation: An introduction to the concept. *Energy policy*, 35(5), 2683–2691.
- Yin, R. K. (2009). *Case study research: Design and methods* (Vol. 5). sage.
- Zolfagharian, M. (2019). How to study transition problems? theories, methods and models. [phd thesis 1 (research tu/e / graduation tu/e), industrial engineering and innovation sciences]. technische universiteit eindhoven. https://pure.tue.nl/ws/portalfiles/portal/115701500/20190123_Zolfagharian.pdf

A

APPENDIX A

A.1 Data Management Plan

Plan Overview

A Data Management Plan created using DMPonline

Title: Governing and scaling aqua thermal energy system innovation in the Fryslân region

Creator: Hadeer Ramdan

Affiliation: Delft University of Technology

Template: TU Delft Data Management Plan template (2021)

Project abstract:

This research will explore how stakeholders within the Wetterwaarmte niche can leverage knowledge sharing, network building, and policy advocacy to promote wider adoption of surface water AE. Ultimately, this research aims to contribute to a successful transition towards a sustainable energy future for Friesland, fueled by the collective power of Wetterwaarmte and a strategically managed socio-technical system.

objective is to develop a framework for the analysis of current governance (arrangements), policies and stakeholder involvement in AE developments and other local cooperative heating and cooling solutions.

This will be achieved through interviews and surveys with key actors in the aquathermal energy systems industry and literature research.

ID: 153564

Start date: 19-04-2024

End date: 19-09-2024

Last modified: 15-07-2024

Figure 11: DMP

Governing and scaling aqua thermal energy system innovation in the Fryslân region

0. Administrative questions

1. Name of data management support staff consulted during the preparation of this plan.

Deepshikha Purwar and Nicola Dintzner

2. Date of consultation with support staff.

2024-06-06

1. Data description and collection or re-use of existing data

3. Provide a general description of the type of data you will be working with, including any re-used data:

Type of data	File format(s)	How will data be collected (for re-used data: source and terms of use)?	Purpose of processing	Storage location	Who will have access to the data
Interview Recording	MP4/AVI	During the interview	Capturing experts' opinions on obstacles, successes, and needs of many stakeholders regarding AE implementation in Friesland	TU Delft One drive	Hadeer Ramdan- and my supervisor (Linda Kamp), Daily Advisor (Nthabi Mohlakoana)
Interview transcripts	.txt	Produced from the interview recording	Capturing experts' opinions on obstacles, successes, and needs of many stakeholders regarding AE implementation in Friesland	TU Delft One drive	Hadeer Ramdan- and my supervisor (Linda Kamp), Daily Advisor (Nthabi Mohlakoana)
Participant's list	Excel spreadsheet	Professional network.	Finding experts in the domain of AE and district heating	TU Delft One drive	Hadeer Ramdan- and my supervisor (Linda Kamp), Daily Advisor (Nthabi Mohlakoana)
Survey Answers	.txt	a survey distributed through partners	Capturing experts' opinions on obstacles, successes, and needs of many stakeholders regarding AE implementation in Friesland. In case of no time is available for interviewing	TU Delft One drive	Hadeer Ramdan- and my supervisor (Linda Kamp), Daily Advisor (Nthabi Mohlakoana)
Report	.pdf	Serves as a record of the process as well as documentation	Long term documentation	TU Delft One drive	Hadeer Ramdan- and my supervisor (Linda Kamp, Thomas Hoppe), Daily Advisor (Nthabi Mohlakoana)

4. How much data storage will you require during the project lifetime?

- < 250 GB

Figure 12: DMP

II. Documentation and data quality

5. What documentation will accompany data?

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- Methodology of data collection

III. Storage and backup during research process

6. Where will the data (and code, if applicable) be stored and backed-up during the project lifetime?

- OneDrive

IV. Legal and ethical requirements, codes of conduct

7. Does your research involve human subjects or 3rd party datasets collected from human participants?

- Yes

8A. Will you work with personal data? (information about an identified or identifiable natural person)

If you are not sure which option to select, first ask your [Faculty Data Steward](#) for advice. You can also check with the [privacy website](#). If you would like to contact the privacy team: privacy-tud@tudelft.nl, please bring your DMP.

- Yes

8B. Will you work with any other types of confidential or classified data or code as listed below? (tick all that apply)

If you are not sure which option to select, ask your [Faculty Data Steward](#) for advice.

- Yes, confidential data received from commercial, or other external partners

Figure 13: DMP

9. How will ownership of the data and intellectual property rights to the data be managed?

*For projects involving commercially-sensitive research or research involving third parties, seek advice of your **Faculty Contract Manager** when answering this question. If this is not the case, you can use the example below.*

This MSC project is taking place as part of the WaterWarmth project, in collaboration with the province of Friesland and several Dutch universities. The IP related to the data is framed by a consortium agreement.
but Also Tu delft will review all the documents before sharing them with the third party

10. Which personal data will you process? Tick all that apply

- Names and addresses
- Email addresses and/or other addresses for digital communication
- Other types of personal data - please explain below
- Data collected in Informed Consent form (names and email addresses)
- Signed consent forms

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Interview:

- company in which they work (name)
- job description, domain of activity
- age : in range of 10 years

Survey:

- years of experience
- job description, domain of activity

11. Please list the categories of data subjects

Data subjects are professionals working in Aquathermal Energy Systems and district heating within companies located around Friesland. Along with Friesland stakeholders in Aquathermal energy systems

The data subjects are the same of the interviews and survey.

12. Will you be sharing personal data with individuals/organisations outside of the EEA (European Economic Area)?

- No

15. What is the legal ground for personal data processing?

- Informed consent

Also Tu delft will review all the documents before sharing with a third party

Figure 14: DMP

16. Please describe the informed consent procedure you will follow:

All study participants will be asked for their written consent for taking part in the study and for data processing before the start of the interview.

17. Where will you store the signed consent forms?

- Same storage solutions as explained in question 6

18. Does the processing of the personal data result in a high risk to the data subjects?

If the processing of the personal data results in a high risk to the data subjects, it is required to perform [Data Protection Impact Assessment \(DPIA\)](#). In order to determine if there is a high risk for the data subjects, please check if any of the options below that are applicable to the processing of the personal data during your research (check all that apply).

If two or more of the options listed below apply, you will have to [complete the DPIA](#). Please get in touch with the privacy team: privacy-tud@tudelft.nl to receive support with DPIA.

If only one of the options listed below applies, your project might need a DPIA. Please get in touch with the privacy team: privacy-tud@tudelft.nl to get advice as to whether DPIA is necessary.

If you have any additional comments, please add them in the box below.

- None of the above applies

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22. What will happen with personal research data after the end of the research project?

- Personal research data will be destroyed after the end of the research project
- Anonymised or aggregated data will be shared with others

Tu delft will review all the documents before sharing with a third party

23. How long will (pseudonymised) personal data be stored for?

- Other - please state the duration and explain the rationale below

All data collected during this project will be preserved as part of the WaterWarmth data (2026).

Figure 15: DMP

23. How long will (pseudonymised) personal data be stored for?

- Other - please state the duration and explain the rationale below

All data collected during this project will be preserved as part of the WaterWarmth data (2026).

24. What is the purpose of sharing personal data?

- For research purposes, which are in-line with the original research purpose for which data have been collected

The personal data may be shared with partners of the Water Warmth Project (Tu/Twente).

25. Will your study participants be asked for their consent for data sharing?

- Yes, in consent form - please explain below what you will do with data from participants who did not consent to data sharing

The data collected during this interview will be anonymized and publicly shared along side of the associated publication. All personal data collected during the interview will be deleted at the latest 1 month after the end of the project

V. Data sharing and long-term preservation**27. Apart from personal data mentioned in question 22, will any other data be publicly shared?**

- All other non-personal data (and code) underlying published articles / reports / theses

interview protocol (questions and themes)
survey questions

29. How will you share research data (and code), including the one mentioned in question 22?

- I will upload the data to another data repository (please provide details below)

Everything will be in the TU-Delft educational repository, in the appendices of the MSc thesis.

31. When will the data (or code) be shared?

- As soon as corresponding results (papers, theses, reports) are published

VI. Data management responsibilities and resources**33. Is TU Delft the lead institution for this project?**

Figure 16: DMP

- No - please provide details of the lead institution below and TU Delft's role in the project

TU Delft is not the lead institution for the whole project. The Friesland Province partners are the lead partner. TU Delft is the leader of Work Package 6

Work Package 6 has the objective to: 'develop a framework for the analysis of current governance (arrangements), policies and stakeholder involvement in AE developments and other local cooperative heating and cooling solutions

Name of (sub)partner	
1.	Province of Fryslân
1.1.	Warm Heeg
1.	Gemeente Leeuwarden
2.1.	Grieneke
1.	Gemeente De Fryske Marren
1.	TU Delft – Faculteit Bouwkunde
1.	TU Delft – Faculteit Techniek, Bestuur en Management
1.	BUILDERS Ecole 'd Ingenieurs
1.	Université Le Havre Normandie
1.	ESIGELEC Ecole d'Ingénieurs Généralistes
1.	Stad Kortrijk
9.1.	Hogeschool West Vlaanderen (HOWEST)
1.	Energent
1.	Stad Mechelen
11.1.	Sub
1.	European Heat Pump Association
1.	EXTRAQT
1.	Danish Board of District Heating
1.	Aalborg CSP
1.	Middelfart Kommune
1.	Lund University – Centre for Sustainability Studies
1.	Hamburgisches WeltWirtschaftsinstitut

Figure 17: DMP

34. If you leave TU Delft (or are unavailable), who is going to be responsible for the data resulting from this project?

TU delft Researcher in the field of energy policy and gender "Nthabi Mohlakoana" <N.Mohlakoana@tudelft.nl>

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35. What resources (for example financial and time) will be dedicated to data management and ensuring that data will be FAIR (Findable, Accessible, Interoperable, Re-usable)?

No additional resources will be required.

Figure 18: DMP

A.2 Human Research Ethics Checklists

Delft University of Technology
HUMAN RESEARCH ETHICS
CHECKLIST FOR HUMAN RESEARCH
(Version January 2022)

IMPORTANT NOTES ON PREPARING THIS CHECKLIST

1. An HREC application should be submitted for every research study that involves human participants (as Research Subjects) carried out by TU Delft researchers
2. Your HREC application should be submitted and approved **before** potential participants are approached to take part in your study
3. All submissions from Master's Students for their research thesis need approval from the relevant Responsible Researcher
4. The Responsible Researcher must indicate their approval of the completeness and quality of the submission by signing and dating this form OR by providing approval to the corresponding researcher via email (included as a PDF with the full HREC submission)
5. There are various aspects of human research compliance which fall outside of the remit of the HREC, but which must be in place to obtain HREC approval. These often require input from internal or external experts such as [Faculty Data Stewards](#), [Faculty HSE advisors](#), the [TU Delft Privacy Team](#) or external [Medical research partners](#).
6. You can find detailed guidance on completing your HREC application [here](#)
7. Please note that incomplete submissions (whether in terms of documentation or the information provided therein) will be returned for completion **prior to any assessment**
8. If you have any feedback on any aspect of the HREC approval tools and/or process you can leave your comments [here](#)

Figure 19: HREC

I. Applicant Information

PROJECT TITLE:	Governing and scaling aqua thermal energy system innovation in the Fryslân region
Research period: <i>Over what period of time will this specific part of the research take place</i>	19/04/2024 to 19/09/2024
Faculty:	TPM(MOT)
Department:	MOT
Type of the research project: <i>(Bachelor's, Master's, DreamTeam, PhD, PostDoc, Senior Researcher, Organisational etc.)</i>	Master's
Funder of research: <i>(EU, NWO, TUD, other – in which case please elaborate)</i>	
Name of Corresponding Researcher: <i>(If different from the Responsible Researcher)</i>	Hadeer Ramdan
E-mail Corresponding Researcher: <i>(If different from the Responsible Researcher)</i>	hramdan@tudelft.nl
Position of Corresponding Researcher: <i>(Masters, DreamTeam, PhD, PostDoc, Assistant/ Associate/ Full Professor)</i>	Master's Student
Name of Responsible Researcher: <i>Note: all student work must have a named Responsible Researcher to approve, sign and submit this application</i>	Linda Kamp
E-mail of Responsible Researcher: <i>Please ensure that an institutional email address (no Gmail, Yahoo, etc.) is used for all project documentation/ communications including Informed Consent materials</i>	L.M.Kamp@tudelft.nl
Position of Responsible Researcher : <i>(PhD, PostDoc, Associate/ Assistant/ Full Professor)</i>	Associate Professor

Figure 20: HREC

II. Research Overview

NOTE: You can find more guidance on completing this checklist [here](#)

a) Please summarise your research very briefly (100-200 words)

What are you looking into, who is involved, how many participants there will be, how they will be recruited and what are they expected to do?

Add your text here – (please avoid jargon and abbreviations)

This research will explore how stakeholders within the Wetterwaarmte niche can leverage knowledge sharing, network building, and policy advocacy to promote wider adoption of surface water AE. Ultimately, this research aims to contribute to a successful transition towards a sustainable energy future for Friesland, fueled by the collective power of Wetterwaarmte and a strategically managed socio-technical system.

objective is to develop a framework for the analysis of current governance (arrangements), policies and stakeholder involvement in AE developments and other local cooperative heating and cooling solutions.

This will be achieved through interviews and surveys with key actors in the aquathermal energy systems industry and Literature research.

- b) **If your application is an additional project** related to an existing approved HREC submission, please provide a brief explanation including the existing relevant HREC submission number/s.

Add your text here – (please avoid jargon and abbreviations)

no

- c) **If your application is a simple extension of, or amendment to,** an existing approved HREC submission, you can simply submit an [HREC Amendment Form](#) as a submission through LabServant.

Figure 21: HREC

H: More on Informed Consent and Data Management

NOTE: You can find guidance and templates for preparing your Informed Consent materials [here](#).

Your research involves human participants as Research Subjects if you are recruiting them or actively involving or influencing, manipulating or directing them in any way in your research activities. This means you must seek informed consent and agree/ implement appropriate safeguards regardless of whether you are collecting any PIRD.

Where you are also collecting PIRD, and using Informed Consent as the legal basis for your research, you need to also make sure that your IC materials are clear on any related risks and the mitigating measures you will take – including through responsible data management.

Got a comment on this checklist or the HREC process? You can leave your comments [here](#).

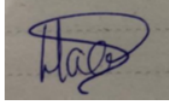
IV. Signature/s

Please note that by signing this checklist list as the sole, or Responsible, researcher you are providing approval of the completeness and quality of the submission, as well as confirming alignment between GDPR, Data Management and Informed Consent requirements.

Name of Corresponding Researcher (if different from the Responsible Researcher) (print)

Hadeer Ramdan

Signature of Corresponding Researcher:



Date: 19/06/2024

Name of Responsible Researcher (print)

Linda Kamp

Signature (or upload consent by mail) Responsible Researcher:



Date: 19/06/2024

V. Completing your HREC application

Please use the following list to check that you have provided all relevant documentation

Required:

- **Always:** This completed HREC checklist
- **Always:** A data management plan (reviewed, where necessary, by a data-steward)
- **Usually:** A complete Informed Consent form (including Participant Information) and/or Opening Statement (for online consent)

Figure 22: HREC

Please also attach any of the following, if relevant to your research:

Document or approval	Contact/s
Full Research Ethics Application	After the assessment of your initial application HREC will let you know if and when you need to submit additional information
Signed, valid Device Report	Your Faculty HSE advisor
Ethics approval from an external Medical Committee	TU Delft Policy Advisor, Medical (Devices) Research
Ethics approval from an external Research Ethics Committee	Please append, if possible, with your submission
Approved Data Transfer or Data Processing Agreement	Your Faculty Data Steward and/or TU Delft Privacy Team
Approved Graduation Agreement	Your Master's thesis supervisor
Data Processing Impact Assessment (DPIA)	TU Delft Privacy Team
Other specific requirement	Please reference/explain in your checklist and append with your submission

Figure 23: HREC

Delft University of Technology
HUMAN RESEARCH ETHICS
PROJECT AMENDMENT FORM
(Version: January 2022)

This project amendment form can be used to request approval for **amending or extending** research which already has recent HREC approval. If you are seeking approval for a new project **related to** an existing approval, then you should submit a standard HREC application as normal.

If you have any questions about your applying for HREC approval which are not dealt with on the [Research Ethics webpages](#), please contact HREC@tudelft.nl

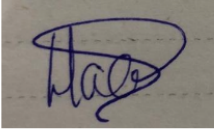
I. Please provide the following information:

Submission number of existing HREC approval	4502
Title of existing HREC approval	Governing and scaling aqua thermal energy system innovation in the Fryslân region
Date of existing HREC approval	
<i>If the amendment is simply a change in personnel, please provide:</i> - the name/s and function/s (eg: researcher with access to confidential data) of the existing personnel - the name/s and function/s of the new personnel - the reason for these changes.	
<i>If the amendment is simply an extension of the original, please provide:</i> - the old end date - the new end date - the reason for this extension	19-09-2024 15-01-2025 - Thesis postponed due to a missing course
<i>For any other amendment/s please summarise:</i>	
What exactly you are proposing to change compared to your original application	
What are the reasons for these changes	
How these changes will affect the potential risks to your participants	
What steps you will take to mitigate against these risks	
How you will address these changes in your DMP and/or Informed Consent	

II. Signature/s

Please note that by signing this checklist list as the sole, or Responsible, researcher you are providing approval of the completeness and quality of the submission, as well as confirming alignment between GDPR, Data Management and Informed Consent requirements.

Figure 24: Extension Form

Name of Corresponding Researcher (if different from the Responsible Researcher) (print)	
	
Signature of Corresponding Researcher:	
Date: 08/10/2024	

Name of Responsible Researcher (print)	
Signature (or upload consent by mail) Responsible Researcher: 	
Date: 08/10/2024	

Figure 25: Extension Form

A.3 Informed Consent Form

Informed Consent Form for Interview on Aquathermal Energy Systems in Friesland

Introduction

This Informed Consent Form is for individuals participating in a research project investigating “Governing and scaling aquathermal energy system innovation in the Fryslân region”. The project is conducted by Professors Linda Kamp, Thomas Hoppe, Nthabi Mohlakoana, BinBin Pearce and Ms. Hadeer Ramdan from Delft University of Technology. This MSc project is taking place as part of the Wetterwaarmte project, in collaboration with the province of Friesland and several Dutch universities. The contact person at Delft University of Technology is Ms Hadeer Ramdan (hramdan@tudelft.nl)

Purpose of the Study

The purpose of this interview is to gather insights and experiences regarding Niche Aquathermal Energy Systems in Friesland using both Multi-Level Perspective and Strategic Niche Management Frameworks. Data collection will be through conducting interviews and surveys with key actors in the aquathermal energy systems industry along with text documents. The data will be used for data analysis and publications including a Master’s thesis, and potentially one or more academic publications. The interview will take roughly 40 to 60 minutes. Your participation will help us understand the benefits, challenges, and overall impact of these systems.

Confidentiality

The data provided will be used for the Wetterwaarmte project and academic purposes. This may include data analysis and publishing. The information provided by the participants will be anonymized, where possible. All information you provide during the interview will be kept confidential. All data or documents collected during this project will be preserved as part of the WaterWarmth data (2026) and reviewed by TUDelft before sharing. The data collected during this interview will be anonymized and publicly shared alongside the associated publication. Your name and other identifying information will be censored and protected in any reports or publications unless you give your explicit consent. The meeting’s recording will be securely stored and transcribed anonymously. All personal data collected during the interview will be deleted at the latest 1 month after the end of the project.

As with any online activity, the risk of a breach is always possible. To the best of our ability, your answers in this study will remain confidential. We guarantee privacy. We will minimize any risks by storing the data collected safely and confidentially at Delft University of Technology, and by anonymizing interview data.

Voluntary Participation

Your participation in this interview is entirely voluntary. You have the right to withdraw from the interview at any time without penalty. You may also choose not to answer any specific questions you feel uncomfortable with.

Questions

Figure 26: Informed consent form

If you have any questions about the study or this consent form, please do not hesitate to ask Ms.Hadeer Ramdan before the interview begins.

Your Consent

By signing this form, you acknowledge that you have read and understood the information provided above. You agree to participate in this interview voluntarily.

Contact Person

The contact person at Delft University of Technology is Ms Hadeer Ramdan (hramdan@tudelft.nl)

Written Consent

Your participation in this study is only possible if you freely and independently sign this consent to authorize us to use the data you provide. If you do not wish to do so, please do not participate in this study.

I hereby declare that:

1. I am 18 years of age or older. (Yes/No)
2. I have been informed about the purpose of this research project on Aquathermal Energy Systems in Friesland. (Yes/No)
3. I understand that participating in this interview is voluntary and I can withdraw at any time. (Yes/No)
4. I have had the opportunity to ask questions about the research and all my questions have been answered to my satisfaction. (Yes/No)
5. I understand that my data will be used for scientific purposes and I have no objection to this as long as my identity remains confidential. (Yes/No)
6. I agree to have the interview recorded. (Yes/No) **(If answer to #6 is NO, then add)**
7. If I do not consent to recording, I understand that the researcher will take notes during the interview. (Yes/No)
8. I understand that I have the right to refuse to answer any questions or withdraw from the interview at any point.(Yes/No)

Figure 27: Informed consent form

9. I understand that anonymized information from this interview may be shared with project researchers and partners.(Yes/No)
10. I agree to participate in this research project without prejudice to my legal or ethical rights. (Yes/No)

Participant:

- Name (printed): _____
- Signature: _____
- Date: _____

I as a researcher, have accurately read out the information sheet to the potential participant and to the best of my abilities, ensured that the participant understands to what they are freely consenting.

Hadeer Ramdan

Interviewer:

- Name (printed): [Your Name]
- Signature: _____
- Date: _____

A copy of this form will be provided to you for your records.

Figure 28: Informed consent form

Dear Participant,

Thank you for agreeing to participate in this interview! My name is Hadeer Ramdan and I'm researching Governing and scaling aquathermal energy system innovation in the Fryslân region. The goal of this interview is to gather your insights and experiences with these systems. The interview will be recorded with your permission, and it will last approximately 40 to 60 minutes. I would like to ask you to review this consent form. It outlines the details of the study and your rights as a participant. Please take your time to read it carefully, and don't hesitate to ask any questions you may have.

Again your participation is greatly appreciated

Thanks In Advance

Best Regards
Hadeer Ramdan

Figure 29: Opening Form

B

APPENDIX B

B.1 Interview Questions

Interview Questions for Aquathermal Energy Systems in Fryslân

Thank you for agreeing to this interview on Governing and scaling Aquathermal Energy Systems in Fryslân , which is part of my thesis research for the Management of Technology master's program at TU Delft. The goal of this interview is to gain insight regarding Niche Aquathermal Energy Systems in Friesland using both Multi-Level Perspectives and Strategic Niche Management Frameworks.

As described in the informed consent form you have received, this interview is scheduled to take one hour and, with your permission, will be recorded. Any questions regarding privacy or data usage you can ask now or at any moment by contacting me or my research supervisor directly with the contact details provided in the informed consent form.

Before we start, do you have any questions? Do I have your permission to start the recording?

First of all, now that the recording is on. Have you read and do you agree to the informed consent statement, shared with you prior to this interview?

Introductory Questions (ca. 5 minutes)

1. Could you briefly introduce yourself, the organization you are affiliated with, and describe your involvement in aquathermal energy in Fryslan?

Stakeholder Analysis (ca. 10 minutes)

2. Who are the key stakeholders involved in aquathermal energy projects in Fryslan?
3. How do these stakeholders collaborate and coordinate within the context of AE projects?
4. Are there any underrepresented or overlooked stakeholders that should be involved?
5. How has your organization and its stakeholders learned from past experiences with aquathermal energy projects? and how have these lessons been incorporated into current projects?

Technical and Operational Aspects (ca. 15 minutes)

6. What are the main technical challenges associated with implementing aquathermal energy systems in Fryslan, considering factors such as water quality, depth, and seasonal variations?
7. How are aquathermal energy systems typically integrated into existing building heating and cooling systems in Fryslan?

Governance and Policy (ca. 15 minutes)

8. What role do government policies and regulations play in promoting or hindering the development of aquathermal energy in Fryslan?
9. How can policy frameworks be adapted to support the growth of aquathermal energy?
10. What are the main challenges and opportunities related to public acceptance and engagement in aquathermal energy projects?

Figure 30: Interview's Questions

11. What role can collaboration between different stakeholders play in overcoming future challenges and realizing the full potential of aquathermal energy?

Economic and Environmental Aspects (ca. 15 minutes)

12. What are the economic factors influencing the viability of aquathermal energy projects in Fryslan?
13. How do you assess the environmental impact of aquathermal energy systems compared to other heating and cooling technologies?

Future Outlook (ca. 10 minutes)

14. What do you see as the main challenges and opportunities for scaling up aquathermal energy systems in Fryslan in the next 5-10 years?
15. How do you envision the role of aquathermal energy within the broader energy mix of Fryslan in the next 5-10 years? are there any specific goals or targets that have been set for aquathermal energy in Fryslan? How do these align with broader energy transition goals in the region?
16. What are potential collaborations or partnerships that could accelerate the adaption of aquathermal energy?

Closing (ca. 5 minutes)

17. Are there any specific documents, studies, or experts you would recommend for further research on aquathermal energy in Fryslan?
18. Do you have any additional insights or perspectives on the future of aquathermal energy in Fryslan?

Figure 31: Interview's Questions

C

APPENDIX C

C.1 Preliminary Stakeholder's map

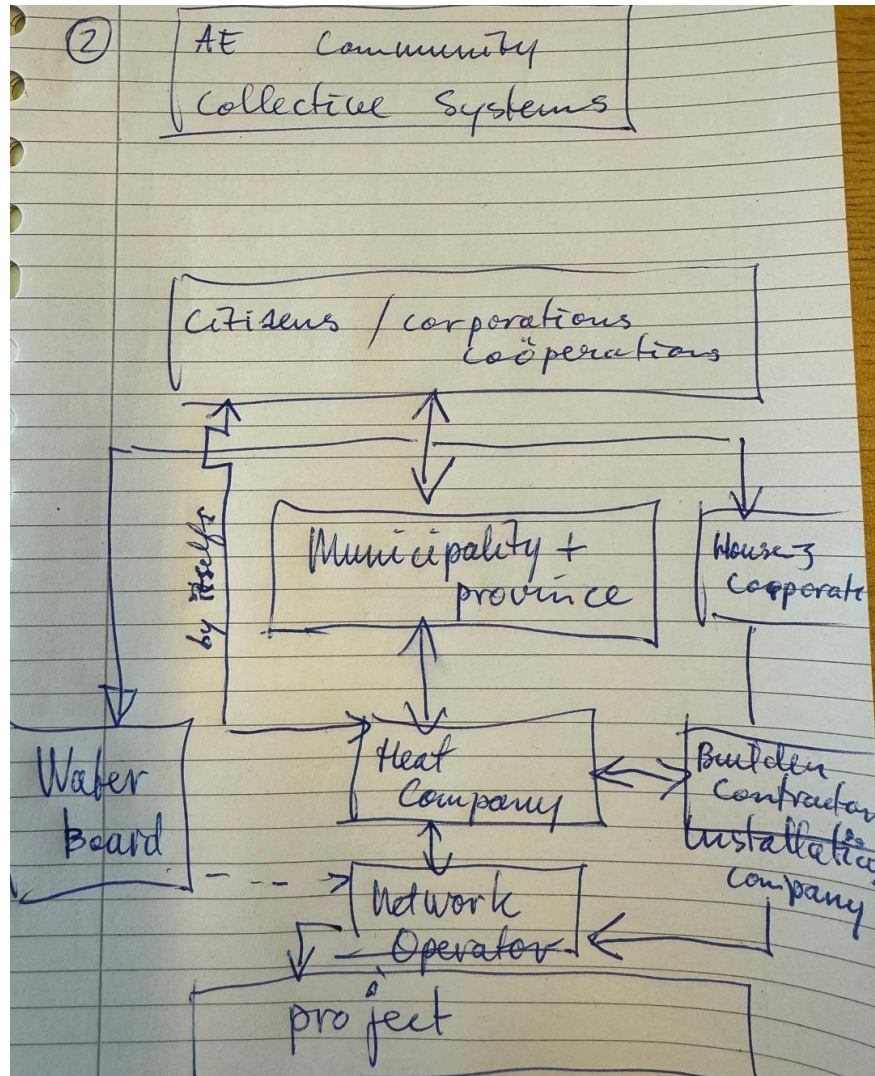


Figure 32: Collective AE system stakeholders' map (MOL, Interview 3, 2024)

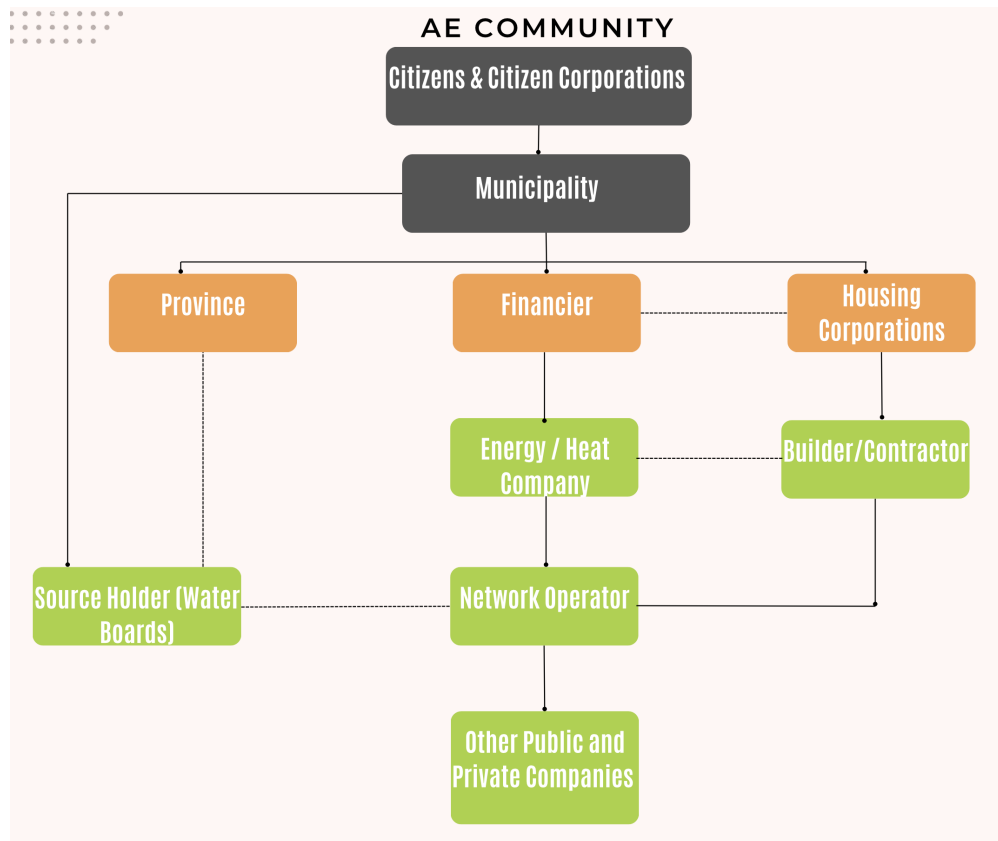


Figure 33: Initial created stakeholder's map