Governance in Hot Water

Exploring the Governance of Aquathermal District Heating Networks in Fryslân

TU Delft

A Master's Thesis by Floris Groot

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Exploring the Governance of Aquathermal District Heating Networks in Fryslân

by

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PREFACE

"To ask the right question is already half the solution of a problem."

- Carl Gustav Jung (1959)

Dear Reader,

The quote above beautifully captures what I see as the essence of my thesis: by asking the right questions, I aim to facilitate the decision-making process to achieve effective and efficient governance designs for the collective, sustainable aquathermal heating infrastructures of the (near) future.

The image on the front is an aerial photograph of Langweer, a small village in Fryslân situated on the edge of the beautiful Langweerderwielen lake. This place is like home to me, as I have been coming there on vacations since my birth. My personal connection to Fryslân and its lakes made the concept of aquathermal energy in that region an immediately appealing research subject when it was first brought to my attention. Although there is currently no aquathermal project in Langweer, I feel the front image illustrates the sheer practical logic of using of Fryslân's characteristic lakes, which are so integrated into Frisian life, as a source for sustainable heat.

I would like to thank several people who were instrumental during my Master's Thesis process. First and foremost, I extend my heartfelt thanks to the members of my graduation committee for their insightful contributions, challenging questions, and constructive feedback. My sincere thanks go to my first supervisor, Ellen, whose invaluable assistance enabled me to complete this research within the aspired timeframe and level of rigor. I deeply appreciated our discussions and am sincerely thankful for your help throughout this process. I also want to thank Neelke for protecting the academic integrity of my thesis, for sometimes crossing that line to contribute insightfully to discussions, and for executing the role of committee chair perfectly. Lastly, I thank Thomas for introducing me to this fascinating subject and for generously making his extensive network of experts available to me.

Secondly, I would like to thank all participants who took the time to speak with me in interviews or discuss my work in the workshop. Your willingness to share your insights made this research possible. Special thanks go out to the people at the Province of Fryslân and the WaterWarmth project, who supported and facilitated my research in numerous ways.

Lastly, I am deeply thankful to my friends and family, who patiently endured my extensive rants and ramblings on the governance of aquathermal district heating networks in Fryslân and its implications. Your support and understanding were invaluable and wholly appreciated.

Before you lies my Master's Thesis. May it offer you the same inspiration and insights it provided me.

Floris Groot
Rotterdam, June 2024

Executive Summary

In a global community working to curb climate change, the Netherlands has set an ambitious goal to achieve a fully sustainable heat supply by 2050, a commitment rooted in the 2015 Paris Agreement. However, as of 2019, 85% of the national heat demand was still met through natural gas, necessitating substantial efforts to promote and implement diverse, region-specific sustainable heating technologies. Aquathermal Energy (AE) presents a promising, yet underexplored, heating technology. Especially in the water-rich province of Fryslân, where it could potentially supply around 60% of the heat demand. Missy Wetterwaarmte, a collaborative project of various Frisian governments, therefore seeks to speed up the development and implementation of collective AE heating systems, or Aquathermal District Heating Networks (ADHNs). Together, they identify a lack of clearly defined and region-specific governance arrangements as a major barrier to ADHN implementation.This study aims to overcome this barrier by developing a decision-making framework to guide policymakers in creating concrete, region-specific governance arrangements for ADHNs in Fryslân, thus enabling their swift implementation and effective governance. Additionally, we seek to enrich academic literature by providing empirical observations on the governance implications of ADHNs in Fryslân and by further operationalizing existing theoretical frameworks for designing governance arrangements for energy infrastructures.

Through our research, we answer the following research question: *What deliberations and considerations should be included in a decision-making framework for designing governance arrangements of aquathermal district heating networks in Fryslân?* In order to do so, we conduct exploratory research using a theoretical framework that integrates the *governance arrangements framework* into the *comprehensive design of energy infrastructures framework*. The research is structured based on the comprehensive design of energy infrastructures framework's four-step approach, with the governance arrangements framework integrated as a structured approach to identifying and interpreting the governance implications of ADHNs in Fryslân, in the third step. We execute the research through qualitative research methods including semi-structured expert interviews, thematic data analysis and an interactive workshop for validation.

We formulate a decision-making framework consisting of three steps: defining system changes, balancing implications, and exploring design directions for governance. The first step guides policymakers to clarify their objectives and define the system changes they aim to achieve, determining whether ADHNs are an end goal or a means to an end, and ensuring resource commitment aligns with these objectives. Policymakers must consider the extent to which ADHNs should be a goal and the level of commitment reflected in resource allocation. The second step focuses on balancing governance implications, prompting policymakers to critically evaluate crucial aspects of ADHN governance. This includes assessing the trade-off between a bottom-up approach to the heat transition versus the standardization and regional integration of technical and governance choices, balancing the risks of premature versus delayed ADHN governance arrangement implementation, and reflecting on the suitability of hierarchical, network-, and market-based governance instruments. This step addresses external concerns about the feasibility and unconventional nature of Frisian governance preferences. In the third step, the framework proposes two governance arrangement design directions for further exploration: dividing governance arrangements into phases tailored to the needs of different stages of ADHN development and implementation, and developing supra-municipal governance arrangements by leveraging regional or provincial structures alongside municipal heating companies to enhance efficiency

and sustainability.

Our research emphasizes and affirms the cross-sectoral, cross-boundary, and multi-level governance challenges associated with the energy transition in academic literature, underscoring the need for clear, region-specific governance arrangements and diverse stakeholder integration in Fryslân and beyond. Additionally, the growing importance of community initiatives, such as energy cooperatives, as noted in numerous recent publications on the governance of energy transitions, is also observed in the governance of ADHNs in Fryslân.

We present a significant theoretical innovation through our integrated theoretical framework, creating a more comprehensive and in-depth tool for analyzing and designing governance for energy infrastructures. This framework enhances analytical rigor by ensuring that governance implications are identified and interpreted for all crucial elements of governance arrangements. The integrated framework's principles and methods can be adapted to other regions and types of energy infrastructures, enhancing its value as a versatile tool for governance analysis and design.

Several limitations affect the validity and applicability of our results, including the early current development stage of ADHNs in Fryslân, potential interview bias from manager-type participants, limited validation due to an incomplete workshop, and the novelty of our theoretical framework integration, which restricts opportunities for comparative analysis and validation.

We suggest that future research builds on this exploratory research on the governance of ADHNs in Fryslân by designing concrete governance arrangements, conducting comprehensive comparative case studies, exploring multi-level governance perspectives, and evaluating outcomes in specific implementations. Additionally, future research should validate and refine our integrated governance framework through application to diverse cases, examine the impact of bottom-up approaches on large-scale energy transitions, and investigate the effects of legal uncertainty on governance decisions and the pace of the energy transition.

We recommend the WaterWarmth project clearly distinguish between individual and collective AE systems, investigate the integration of energy communities in formalized governance and ownership structures, assess the impact of potential regulatory changes on ADHN governance, and expand stakeholder exploration in ADHN governance. For governments in Fryslân, we advise designing more concrete governance arrangements for ADHNs, establishing specific ADHN location designations, critically assessing municipal capacities to manage heating companies, fostering public-private partnerships, and integrating ADHN policy with new housing projects.

CONTENTS

List of Acronyms

Acronym	Definition
5GDHC	Fifth Generation District Heating and Cooling
ADHN	Aquathermal District Heating Network
AE	Aquathermal Energy
ATES	Aquifer Thermal Energy Storage
COSEM	Complex Systems Engineering and Management
DH	District Heating
DHN	District Heating Network
DSO	Distribution System Operator
EIG-DE	Sustainable Energy and Innovation Fund Gelderland (Energie en Innovatiefonds Gelderland - Duurzame Energie)
FET	Frisian Energy Platform (Friese Energietafel)
FSFE	Frisian Clean Energy Fund (Fûns Skjinne Fryske Enerzjy)
GWIB	Gelderland Heating Infrastructure Company (Gelders Warmte-Infra Bedrijf)
LEF	Limburg Energy Fund (Limburgs Energie Fonds)
PPP	Public-Private Partnership
RES	Regional Energy Strategy
STES	Seasonal Thermal Energy Storage
TEO	Thermal Energy from Surface Water (Thermische Energie uit Oppervlaktewater)
TES	Thermal Energy Storage
TSO	Transmission System Operator
WCW	Collective Heating Law (Wet Collectieve Warmte)
WSHP	Water Source Heat Pump

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INTRODUCTION

In this chapter, we introduce the research by describing the research problem addressed, reviewing the existing relevant academic and professional literature, stating the research objectives and research questions, explaining the connection of the research to the master's program, and providing the outline of this thesis.

1.1. RESEARCH PROBLEM

In this section, we introduce the research problem we address in this research.

In accordance with the 2015 Paris Agreement, the Netherlands has committed to a heat transition, aiming to supply the built environment in the country with heat from fully sustainable sources by 2050 (Rijksoverheid, 2019b; UNFCCC, 2015). As of 2019 however, approximately 85% of the heat demand in the Dutch built environment was still supplied through the use of natural gas, which is a fossil fuel (Segers et al., 2019). Therefore, significant efforts are still required to transition to a sustainable heat supply in the Netherlands. To effectively meet the national heat transition goals, and due to the regional and local differences in context and circumstances in the Dutch built environment, it is crucial to promote the development and implementation of various technologies tailored to the specific needs and circumstances of each neighborhood (NP RES, 2020; Rijksoverheid, 2019a).

Aquathermal Energy (AE) is a sustainable heating technology, that extracts thermal energy from water to provide heating for buildings, offering a sustainable alternative to fossil fuel and an efficient alternative to more conventional air-based heat pumps (Kleiwegt et al., 2023; WaterWarmth, n.d.). In the Netherlands specifically, surface water is an interesting potential source for AE systems, with an estimated thermal potential capable of supplying 40% of the national heat demand from the built environment (NP RES, 2020). Based on the high potential of AE and the need for promoting and developing multiple sustainable heating technologies, a nation-wide 'Green Deal Aquathermal Energy' was reached as part of the Dutch climate accord of 2019 (Rijksoverheid, 2019a).

The high surface-water AE potential in the Netherlands is specifically true for the Province of Fryslân. Fryslân is known for its characteristically abundant lakes and waterways, which means AE from surface water could potentially supply around 60% of the heat demand in the province (Provincie Fryslân, 2021). The nationally stated AE ambitions in the Green Deal, combined with this high potential, have led the Province of Fryslân and its municipalities to commit themselves to becoming the most important AE region in the Netherlands, and specifically to connect 60,000 homes in Fryslân to collective surface-water aquathermal

systems by 2030 (Missy Wetterwaarmte, 2024; Provincie Fryslân, 2021). In this study, we focus on collective surface-water AE heating infrastructures, which we will call: Aquathermal District Heating Networks (ADHN).

AE is an underexplored sustainable heating technology, resulting in a significant knowledge gap, specifically on its governance (T. Hoppe et al., 2024). Establishing timely AE policies and governance structures is crucial for its development in Fryslân. Active collaboration between public and private actors is necessary to achieve meaningful results. Specifically, the Frisian task force for AE, 'Missy Wetterwaarmte,' identifies governance as one of the major bottlenecks to realizing ADHNs in the region, stating the lack of clearly defined governance structures currently hinders the development and implementation of ADHNs in the region. (T. Hoppe et al., 2024; Missy Wetterwaarmte, 2024). Therefore, despite ambitious goals, no ADHNs have yet been realized in Fryslân (Provincie Fryslân, n.d.-b). Moreover, knowledge on suitable governance structures for ADHNs is a white spot in general (Van der Schoor & Van der Windt, 2023; WaterWarmth, 2024).

Governance concerns the societal steering of economic activities through structures that shape the process of coordination between interdependent actors to achieve common gains (Bevir, 2012; Treib et al., 2007; Williamson, 1998). We define these 'structures' as governance arrangements, which are "specific rules, processes, and instruments that structure the interactions between public and/or private entities to realize collective goals for a specific domain or issue" (Termeer et al., 2011, p. 161). As said, the lack of clearly defined governance arrangements inhibits the realization of ADHNs. This is because it leaves open the question of who should take action, which instruments should be leveraged, the platform through which science should inform policy, the timing of actions, leadership responsibilities and forms, alignment with other policy sectors, framing of actions, and the appropriate form of leadership to be taken, thereby limiting the realization of ADHNs (Termeer et al., 2017).

In response to the bottleneck caused by unclear governance designs, and in parallel with the multi-year EU-funded research program 'WaterWarmth'—which includes partners such as TU Delft—Missy Wetterwaarmte has set a specific goal for 2024. This goal is to "investigate various governance models for both the short and long term, compare and evaluate them, and facilitate administrative decision-making" (Missy Wetterwaarmte, 2024, p. 3).

This study aims to fulfill this goal for Missy Wetterwaarmte by conducting exploratory research into governance arrangements for ADHNs in Fryslân. It will investigate the governance implications of ADHNs in the region and explore possible governance arrangement design directions. By doing so, we also contribute to the broader WaterWarmth research project.

1.2. LITERATURE REVIEW

In this section, we review the existing literature on topics relevant to this research. First, we define what ADHNs are. Second, we give a brief overview of the academic literature on governance and the governance of energy infrastructures specifically before summarizing the existing relevant scientific- and professional literature on the governance of ADHNs. Finally, we define the academic knowledge gap that this research aims to fill. The core theoretical concepts used in this research are more thoroughly defined based on academic literature in Chapter 2.

1.2.1. AQUATHERMAL DISTRICT HEATING NETWORKS

AE concerns the extraction of thermal energy from drinking-, waste- or surface water (T. Hoppe et al., 2024; Jung et al., 2021). In general, AE-systems for the built environment use a heat exchanger to extract heat from a water source, which is then heated further by an electricity-powered Water Source Heat Pump (WSHP) (Jung et al., 2022). These AE-systems, sometimes also called WSHP-systems, can either be used for individual

homes or buildings, or applied to multiple buildings through a collective system. The scope of this research is limited to the governance of collective, surface water-source AE-systems.

Collective aquathermal systems use a District Heating Network (DHN) to deliver heat to between tens to thousands of homes (Kleiwegt et al., 2023; Kruit et al., 2018; Van der Schoor & Van der Windt, 2023). A DHN is a network of insulated pipes that distribute heat, using water as a conduit, to the built environment (Lake et al., 2017; Lund et al., 2018; Mahzouni, 2019). In this study, we will call collective aquathermal systems: Aquathermal District Heating Networks (ADHNs). DHNs range from networks that directly deliver high-temperature heat for direct use to more modern variants delivering low-temperature heat that requires a decentral heat pump, as well as delivering cold for cooling (Lund et al., 2018; Massey et al., 2022; Topal et al., 2022).

The most modern variants of (A)DHNs are called 'Fifth Generation District Heating and Cooling (5GDHC) systems. These systems use the lowest system temperatures in combination with Seasonal Thermal Energy Storage (STES) to make use of seasonal differences in temperatures, use summer heat for winter heating, and winter cold for summer cooling (Boesten et al., 2019; Gjoka et al., 2023; Schibuola & Scarpa, 2016). In the Netherlands, STES is most commonly implemented using Aquifer Thermal Energy Storage (ATES), meaning the storage of thermal energy in underground water reservoirs (Kruit et al., 2018).

1.2.2. THE GOVERNANCE OF ADHNS

Infrastructures are the systems that support "the basic metabolism and signal processing of society" in modern economies according to Weijnen and Correljé (2021, p. 19). More concretely, infrastructures are physical networks that transport a flow through a conduit to connect suppliers with demand (Neuman, 2006). Therefore, ADHNs are infrastructures, as they use piping (the physical infrastructure) to transport thermal energy (the flow) through water (the conduit) from a production site to consumers.

On the other hand, governance is the societal steering of economic activities through structures that shape the process of coordination between interdependent actors to achieve common gains (Bevir, 2012; Treib et al., 2007; Williamson, 1998). Specifically in the heat transition, this means governance is concerned with the division of power over- and access to heating infrastructures between (levels of) government, public actors, private actors and citizens (Büttner & Rink, 2019; Henrich et al., 2021; Herreras Martínez et al., 2022; Scholten & Künneke, 2016).

Because the governance of ADHNs specifically has been sparsely researched, we first look to the literature on the governance of DHNs in general. The governance of DHNs typically consists of a combination of (local) government policies and regulatory frameworks that ensure the (local) governments core values and policy goals are met by the DHN, which can for instance be the equitable distribution of heat, efficiency standards, and sustainable practices (Hawkey, 2014; Lavrijssen & Vitéz, 2021). DHN governance frequently involves public-private partnerships, where municipal authorities oversee strategic planning and regulatory compliance, while private companies manage daily operations and infrastructure maintenance (Hawkey & Webb, 2012; Nciri & Miller, 2017). Additionally, governance may include mechanisms for community involvement and feedback to ensure the networks meet local needs and preferences. (Ancona et al., 2022; Ayrault & Aggeri, 2021; Cary, 2015; Hawkey & Webb, 2012; Lavrijssen & Vitéz, 2021; Nciri & Miller, 2017).

Effective governance is a major prerequisite to utilize the significant potential of AE as a heating source for DHNs in the Netherlands, according to Van der Schoor and Van der Windt (2023), which is exemplified by practices such as integrating ADHNs into energy community projects, high levels of local resident involvement, and strong municipal support. Additionally, the substantial investment needs and the necessity for tailored governance frameworks of ADHNs pose a significant challenge to their effective implementation, exploitation and governance. To address these issues, collaborative governance practices seem a fruitful solution space (Van der Schoor & Van der Windt, 2023).

In the governance of ADHNs in the Netherlands, differing actor roles can be distinguished in the process of developing projects, and in the aquathermal heating chain (Kleiwegt et al., 2023; Van Popering-Verkerk et al., 2021). In this study, we will focus on the division of roles and responsibilities in the aquathermal heating chain. Van Popering-Verkerk et al. (2021) distinguish four roles in the aquathermal heating chain, namely; the source holder (water source owner), producer (extracts and produces heat), transporter/distributor (delivers heat) and retailer (handles delivery, billing, administration, and customer service). Optionally, the end-users can also be included in this heating chain, however they are not a responsibility to be divided in a governance arrangement.

The division of roles, responsibilities and ownership in the aquathermal heating chains can be configured in various ways: dispersed among actors, integrated into one actor, or a hybrid. Moreover the involved actors can be public, private, somewhere in between, or public-private partnerships. In addition to the roles in the heating chain, Kleiwegt et al. (2023) and Van Popering-Verkerk et al. (2021) state that it is essential to consider the integration of technology, area, and governance, which aligns with the comprehensive design framework by Scholten and Künneke (2016), which argues the same.

To come to a final design for the governance of ADHNs, several phases have to be progressed through. First, all options are kept open and an exploration plan is developed. Then, governance preconditions are examined and viable options are identified. Finally, a variants are assessed and one or a hybrid is chosen (Van Popering-Verkerk et al., 2021). After choosing a design, it is implemented and the sustainability of the design is monitored.

The governance of AE in Fryslân is specifically studied in Van de Witte (2023) by analyzing the infrastructures through a framework of three ideal-typical governance modes, hierarchical-, network- and market governance. The study finds the governance of AE to be a hybrid structure, predominantly consisting of network governance (Van de Witte, 2023). Effective AE governance in the region relies on high network diversity, direct communication, and a balance between bottom-up and commercial approaches. Additionally, metagovernance can play a significant role in fostering transparency, openness, and collaboration among stakeholders to address key issues and ensure project success (Van de Witte, 2023).

Moreover, according to T. Hoppe et al. (2024), it is crucial for policy-making to keep pace with the development and scaling of AE innovation in Fryslân. Implementing large-scale AE projects is deemed "not possible" without active collaboration between public and private actors, necessitating the formation of public-private partnerships (T. Hoppe et al., 2024, p. 39). Moreover, effective governance of AE in Fryslân requires aligning efforts across different sectors.

1.2.3. ACADEMIC KNOWLEDGE GAP

Despite the growing recognition of AE as a sustainable heating solution, research on its governance remains notably scarce. A systematic literature search conducted in preparation for this thesis revealed a significant lack of scientific literature on the governance of AE systems in general and collective systems in particular. Moreover, the WaterWarmth research project explicitly states the underexplored nature of AE governance as a reason for its 'Work Program 6' concerning governance (WaterWarmth, 2024). Specifically, academic literature on the governance of ADHNs in Fryslân is limited to T. Hoppe et al. (2024) and Van de Witte (2023). The former even explicitly identifies the governance of AE in Fryslân as a suitable subject for further academic research. However, neither of these articles directly applies governance design frameworks to ADHNs in Fryslân. Consequently, there is a clear academic knowledge gap regarding the considerations and deliberations involved in designing governance arrangements for ADHNs, both in general and specifically within the Fryslân region.

Furthermore, there is a lack of sufficiently operationalized theoretical frameworks to structure the design

of governance arrangements for energy infrastructures such as ADHNs. In their article presenting the comprehensive design of energy infrastructures framework, Scholten and Künneke (2016) encourage the further operationalization of their design framework, stating: "the framework remains untested and insufficiently operationalized and scrutinized" (p. 19).

Therefore, in this research we will take a step in the concrete operationalization of the four-step approach to comprehensively designing the governance-side of energy infrastructures and in doing so we will apply a governance design framework to ADHNs in Fryslân, which has not been done before. Thus we can add to the existing academic knowledge by filling the identified gaps in the literature.

1.3. RESEARCH OBJECTIVE AND RESEARCH QUESTIONS

In this section, we state the research objective this research will address and formulate the research questions we seek to answer to that end.

In this research, we develop a decision-making framework to guide governments in Fryslân and their policymakers in the future implementation of governance arrangements for ADHNs. Given the diverse circumstances, technical specifications, and the lack of concrete real-world examples of ADHNs in Fryslân, designing a definitive governance arrangement would be highly theoretical and speculative. Therefore, instead of proposing a definitive governance arrangement, the framework will present a set of considerations and deliberations for policymakers to use in the process of designing governance arrangements for ADHNs post-pilot phase. Therefore, our objective is to formulate a decision-making framework which will equip governments at all levels in Fryslân with a structured approach to design governance arrangements for ADHNs specifically suited to the region, thereby streamlining the governance arrangement design process and facilitating the implementation of ADHNs in Fryslân. Based on this research objective, we formulate the following main research question:

What deliberations and considerations should be included in a decision-making framework for designing governance arrangements for aquathermal district heating networks in Fryslân?

In order to effectively formulate the deliberations and considerations in a decision-making framework for the design of governance arrangements of ADHNs in Fryslân, we utilize a four-step approach to comprehensively designing energy infrastructures which is explained in Chapter 2. Based on the four-step approach, we formulate three subquestions. The first subquestion concerns the first and second step of the comprehensive design framework and reads:

1. *What are the distinctive characteristics of the Frisian heating system, and how will the introduction of aquathermal district heating networks alter this system?*

The second subquestion corresponds to the third step in the comprehensive design framework and reads:

2. *What are the implications of the changes to the Frisian heating system for governance arrangements?*

The third subquestion addresses the fourth and final step in the comprehensive design framework and reads as follows:

3. *What governance arrangement designs exist for aquathermal district heating networks, in- and outside of Fryslân, and what are their characteristics?*

By answering the subquestions, we will be able to formulate an answer to the main research question of this study, through the definition of a decision-making framework for the future implementation of governance arrangements for ADHNs in Fryslân, based on the considerations and deliberations that are identified through this research, in Chapter 7.

1.4. SOCIETAL RELEVANCE

In this section, we elaborate on the societal relevance of this research.

By conducting this research, we contribute to efforts in mitigating climate change. Through the formulation of a decision-making framework for the design of governance arrangements for ADHNs, we aim to facilitate the realization of a sustainable heat supply in the built environment of Fryslân. In doing so, we advance Frisian and Dutch climate goals by contributing to the concrete mitigation of greenhouse gas emissions achieved by replacing gas-fueled heating infrastructure in Fryslân. Moreover, the realization of ADHNs in Fryslân can also serve as a showcase for the technology's viability and the effective governance thereof. By contributing to these efforts, we indirectly promote the future adaption of this sustainable heating technology outside of Fryslân, which also promotes climate goals on multiple scales. Therefore, this research contributes to local, regional, national and global climate change mitigation objectives.

The societal relevance of our research extends beyond environmental benefits. As stated by the Province of Fryslân, developing ADHNs will provide the region with significant economic opportunities (Provincie Fryslân, 2021). This will lead to regional wealth creation and economic development through the establishment of new, green jobs that have a place in the sustainable economy of the future. Moreover, replacing gas-powered heating infrastructure promotes energy independence. The Russian invasion of Ukraine and the phasing out of Dutch natural gas production have made natural gas much less appealing for use from a geopolitical and strategic autonomy perspective (Sampedro et al., 2024). By promoting the implementation of an alternative energy source for heating, we advance the energy independence of Dutch society, thereby enhancing the security and robustness of Frisian and Dutch society in general.

Furthermore, our research contributes to broad societal benefits by enhancing the effectiveness and efficiency of the governance of heating infrastructures, which fulfill societal needs (Weijnen & Correljé, 2021). By providing a structured approach to decision-making in the design process of governance arrangements for ADHNs, ensuring that the appropriate considerations and deliberations are included in the design process, we contribute to the suitability and effectiveness of eventual governance arrangements for their intended goals, ultimately resulting in better societal outcomes (Termeer et al., 2011; Van der Schoor & Van der Windt, 2023).

In summary, our research addresses the urgent need for sustainable heating solutions in Fryslân and contributes to the global fight against climate change. In doing so, we are also promoting energy independence, regional economic development and the effective governance of energy infrastructures. By providing a clear and actionable decision-making framework, we empower policymakers to make informed decisions that promote sustainability, resilience, and good governance. Our work thus aligns with and directly promotes overarching societal interests.

1.5. ACADEMIC RELEVANCE

In this section, we delineate the academic relevance of this research.

First and foremost, through this research, we seek to add empirical observations of the governance of Aquathermal District Heating Networks (ADHNs), specifically in Fryslân. These empirical observations are crucial for academia as they provide concrete data and real-world insights that enhance our understanding

of how ADHNs operate within their specific socio-technical contexts. By studying the actual governance implications, challenges, and outcomes in Fryslân, we contribute valuable information that can be used to validate, challenge, or refine existing academic theories even outside of this particular thesis. This research enriches the academic knowledge base with a comprehensive exploration of the governance implications of ADHNs in the Frisian socio-technical system, offering a foundation for further research on ADHNs and their governance, both inside and outside of Fryslân, as well as the governance of the heating transition in general.

Second, we aim to provide a theoretical innovation by adding an operationalization to Scholten and Künneke's (2016) comprehensive design of energy infrastructures framework. We will achieve this by integrating Termeer et al.'s (2017) governance arrangement framework into Scholten and Künneke's model, specifically as step three of their four-step approach. This integration, detailed further in Chapter 2, contributes to the operationalization of the comprehensive design of energy infrastructures framework, which the authors themselves have called for (Scholten & Künneke, 2016, p. 19). By doing so, we enhance the academic depth of theoretical tools available for comprehensively analyzing and designing energy infrastructures from a socio-technical perspective.

1.6. RELEVANCE TO COSEM

In this section, we substantiate the relevance of this Master's Thesis research to the Complex Systems Engineering and Management (COSEM) program and the COSEM energy track. This research and its subject contain several core elements of the program and offers a comprehensive exploration of a complex socio-technical system — the central focus of COSEM (TU Delft, n.d.).

The development of ADHNs in Fryslân constitute a clear example of a complex system, for three main reasons. Firstly, the system is a multi-actor system, involving at least the Province, energy companies, citizens, water boards and municipalities as stakeholder. Intervening in the system will therefore require a multi-actor decision-making process, as is taught in SEN114. Secondly, the deep uncertainties involved in the system, regarding for instance; the development of heating technology; (inter)national legislation and regulation; public acceptance of heating technologies, and; economic viability of this specific form of heating supply. Thirdly, the system is interdisciplinary in the sense that it involves technical, institutional, governance, economic and environmental aspects and will therefore have to be studied through an interdisciplinary lens.

Furthermore, ADHNs are clear examples of socio-technical systems because they involve both sociological and technical dimensions. The sociological dimension of the system stem from the impact this specific heating supply has on communities and people within the system, as well as the interactions between different stakeholders. The technical dimension is concerned with the implications of specific technological specifications of the aquathermal heating infrastructures to be implemented. In this system, the sociological and technical dimensions of the system interact with each other and it should therefore be studied integrally as a socio-technical system, as is at the core of the COSEM program.

Moreover, this study aims to formulate considerations and deliberations that allow policymakers in Fryslân to design governance arrangements for ADHNs. This aligns closely with COSEM's core aspect of designing interventions in complex socio-technical systems. While this study will not produce a concrete design, we will 'design' a decision-making framework to facilitate the design process of an intervention in these socio-technical systems.

Lastly, the research subject of this thesis aligns closely with the Energy Track within the COSEM program. The heat transition is a core aspect of the wider energy transition towards sustainable energy supply, and AE represents a significant technology in the heat transition, especially in Fryslân. By studying the governance aspects of this sustainable heating technology, we will closely study energy systems in the form of heating

supply, in line with the Energy track.

Therefore, we can conclude that by studying the governance of ADHNs in Fryslân, we are conducting research on a topic closely related to the core principles of the COSEM Master Program and Energy Track.

1.7. OUTLINE OF THE RESEARCH

In this section, we outline the structure of this report.

In Chapter 1, we introduce the research problem, review existing literature, state the research objectives and questions, and explain the connection of this research to the COSEM Master's program. Chapter 2 formulates the theoretical framework, defining core concepts and outlining a structured approach to analysis and interpretation. In Chapter 3, we describe the methodology used to carry out the research, detailing the overall research approach and specific methods employed. Chapter 4 provides a description of the system into which ADHNs will be introduced in Fryslân, analyzing the technical and governance aspects relevant to the design of ADHN infrastructures in the region. In Chapter 5, we identify and interpret the implications of introducing ADHNs to the Frisian heating sector, focusing on the future governance arrangements needed to manage them. Chapter 6 explores possible design directions for future governance arrangements for ADHNs in Fryslân. In Chapter 7, we formulate a decision-making framework for designing suitable governance arrangements for ADHNs in Fryslân, aimed at facilitating a structured and comprehensive decision-making process for policymakers in the region. Chapter 8 discusses the research's results, academic and societal contributions, theoretical and methodological limitations, and suggestions for future research. Finally, Chapter 9 presents the research conclusions and gives policy recommendations.

2

THEORETICAL FRAMEWORK

In this chapter we define the theoretical framework for this study. The theoretical framework acts as the context in which the research subject is studied, and as a lens through which collected data is analysed and the results interpreted (Kivunja, 2018). The theoretical framework guides how empirical observations should be interpreted in the context of developing a decision-making framework for the design of governance arrangements for ADHNs in Fryslân. Furthermore, the theoretical framework structures our approach to formulating a decision-making framework.

First, we define the concept of governance from an institutional economics perspective and what the concept of governance means in the context of energy infrastructures. Second, we integrate the systems engineering approach to designing energy infrastructures with an institutional economics approach. Furthermore, we describe the comprehensive design of energy infrastructures framework of which the four-step approach will act as the backbone structure of this research. Third, we further define how we will interpret the governance implications of ADHNs by using the governance arrangements-framework, and how we use this framework to further operationalize the comprehensive design-framework. Lastly, we define the framework within which current design directions for the governance of ADHNs are conceptualized, based on existing professional literature. For further clarification, the outline of this chapter and the structure of the theoretical framework are also schematically visualized in Figure 2.1.

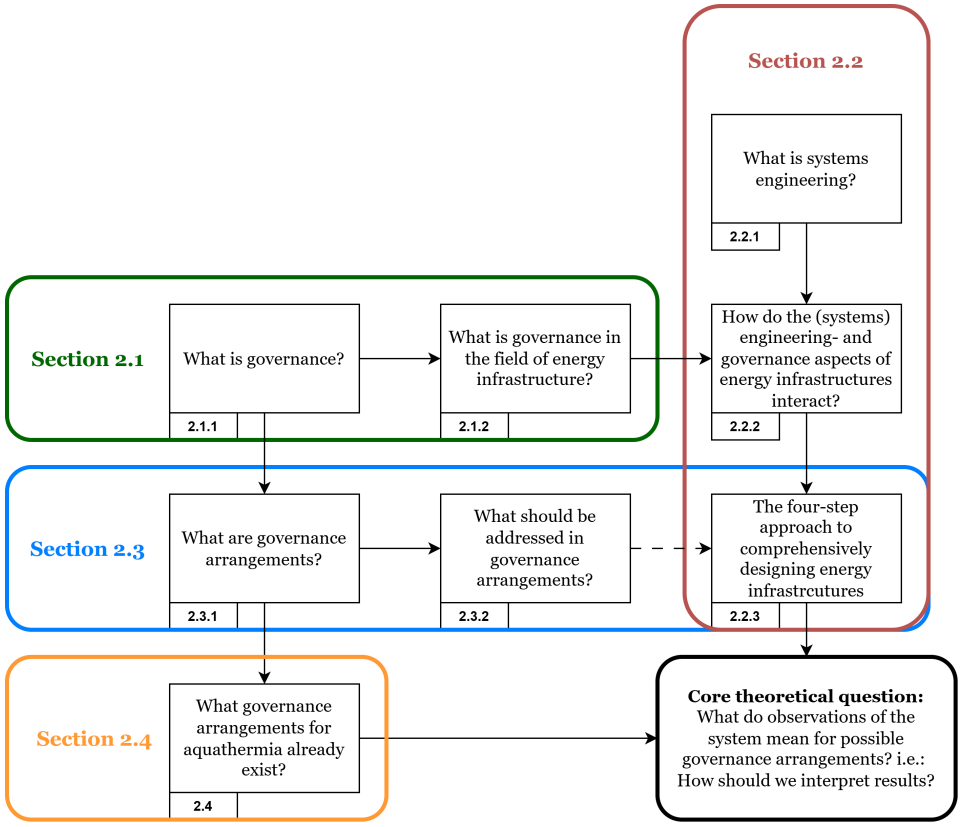

Figure 2.1: Schematic representation of the theoretical framework and of the outline of this chapter.

2.1. INSTITUTIONS AND GOVERNANCE

In this section, we define institutions and specifically governance from an institutional sense based on the existing academic literature.

Institutions are collectively accepted systems of rules that enable the creation of institutional facts, granting specific powers to entities that wouldn't exist without those rules (Hodgson, 2006). They are "the humanly devised constraints that structure political, economic and social interaction," comprising both formal rules and informal constraints (North, 1991, p. 97). Institutions structure the processes that lead to the development, implementation, and management of economic structures and artifacts, such as those related to energy production and usage in the built environment. Using this definition, Williamson (1998) defines a 'four-layer model' shown in Figure 2.2. This model identifies four levels of institutions that influence each other both upwards and downwards.

The first layer, 'Embeddedness,' is viewed as a given for economic purposes, with institutions changing over centuries or millennia. Influenced by traditions and religion, these institutions cannot be 'designed' but have a lasting impact on societal conduct (Williamson, 1998, p. 27).

The second layer, 'Institutional Environment,' concerns the economics of property rights and is also known as the 'rules of the game.' These include laws, regulations, and policies that form the framework for economic activity (Williamson, 1998). Changes at this level are typically incremental, leading to a distinct institutional environment over decades or centuries.

Together with the second layer, the third layer, described in the next subsection, forms the core of New Institutional Economics.

The fourth layer, 'Resource allocation and employment,' involves the operational aspects of economic

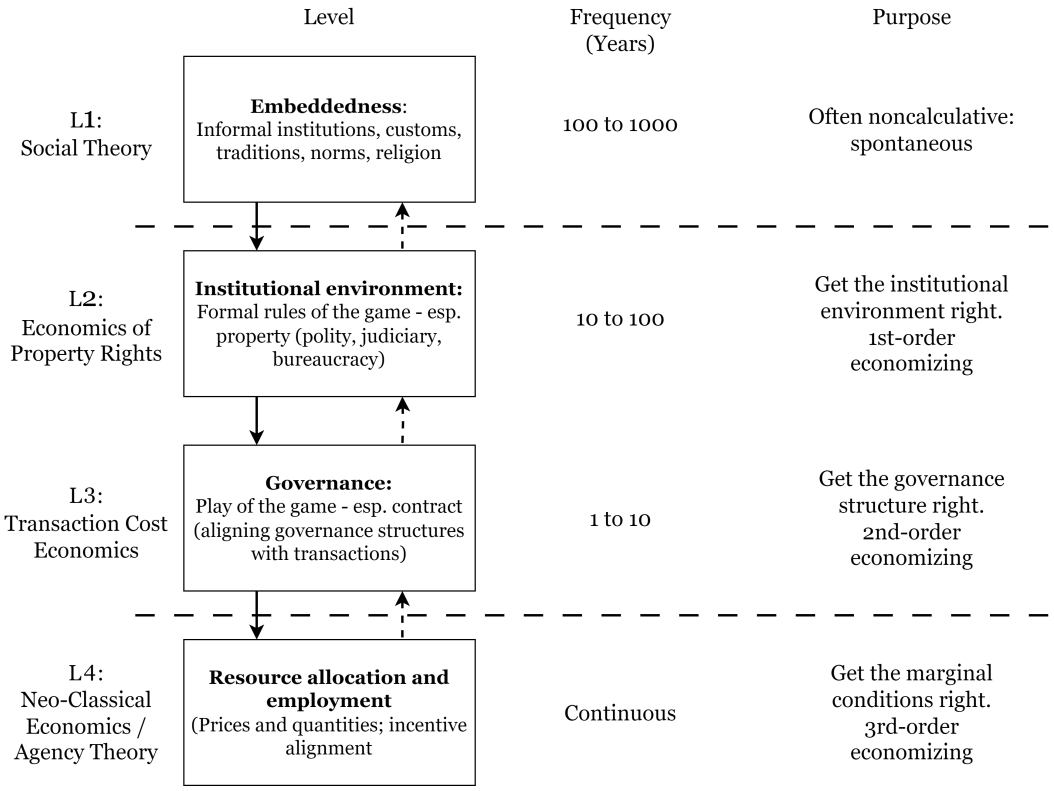

Figure 2.2: The four layer model for the economics of institutions (Williamson, 1998, p. 26).

systems. This layer manifests the outcomes of the preceding layers in resource allocation and employment practices, encompassing day-to-day transactions and micro-level decisions analyzed using neo-classical economics and agency theory (Williamson, 1998).

2.1.1. GOVERNANCE

The third layer of Williamson's four-layer model, 'Governance,' focuses on the mechanisms, frameworks, and strategies that define the "play of the game" within the broader context set by the first two layers (Williamson, 1998). Here, the analysis shifts to the specific ways transactions are governed and coordinated. Governance structures, ranging from market-based to hierarchical organizations ('firms'), and various hybrids in between, help economic actors manage cooperation, competition, and exchange complexities. This analysis identifies the most suitable governance form for specific transactions, considering factors like asset specificity, uncertainty, transaction frequency, and opportunism.

The term governance has gained popularity in public and academic discourse since the late 20th century, leading to a somewhat vague specific meaning (Bevir, 2012). Commonly, governance refers to something "broader than government," using networks of actors to achieve objectives (Kjaer, 2004). Recently, governance has been associated with a shift from traditional hierarchical government to a more complex approach based on stakeholders and cooperation (Bevir, 2012). Instead of using pure hierarchical tools, governance is more collaborative, with governments, markets, citizens, and NGOs cooperating in networks (Bevir, 2012). This "societal steering" involves coordination between interdependent actors based on rule systems (Treib et al., 2007, p. 3). Governance creates order to realize mutual gains between stakeholders, balancing government interference and societal independence, structuring social organization and coordination (Bevir, 2012; Treib et al., 2007; Williamson, 1998).

Governance has distinct characteristics crucial for analysis and design. It integrates actors and institutions across various government levels and policy sectors (Bevir, 2012). Governance, through structuring the rules of the game, seeks to create legitimacy for allocating public resources via democratic means or efficiency (Kjaer, 2004). It involves a broad range of stakeholders in managing specific issues, forming networks, known as network governance (Bevir, 2012).

In this study, we define governance as the societal steering of economic activities through structures that shape the coordination process between interdependent actors to achieve common gains (Bevir, 2012; Treib et al., 2007; Williamson, 1998).

2.1.2. THE GOVERNANCE OF ENERGY INFRASTRUCTURES

The general transition in recent decades from government to governance as observed by Bevir (2012) and Kjaer (2004) can also be observed in the development of energy infrastructure governance over past decades. In the past, energy infrastructures were mostly governed as vertically integrated public monopolies, with governments controlling most or all aspects of the planning, construction and operation (Scholten & Künneke, 2016). However, this 'government' approach to governing energy infrastructures has, through the liberalization and unbundling of energy infrastructures in the late 1990s, developed into a more complex 'governance' approach to governing, involving numerous public-, private- and nonprofit actors and market designs (Künneke & Finger, 2009; Newbery, 1997). Parallel to the governmental shifts toward liberalization and unbundling, which have conceived a governance- rather than government-minded management of energy infrastructures, the technological evolution of these infrastructures themselves has also enhanced their receptiveness to more intricate governance structures beyond traditional hierarchical models. This has cemented the prevalence of multi-scale and cross-sector interactions within and between energy infrastructures, signifying a new norm in their operational dynamics and a need for complex, multi-actor-based management structures (Weijnen & Correljé, 2021).

By synthesizing the earlier definitions of energy infrastructures (Chapter 1), governance in general (defined in the previous section) and the remarks in the previous paragraph, we define the governance of energy infrastructures is as the societal steering of economic interactions between public-, private- and nonprofit actors that envelop the operation of physical networks aimed at connecting supply and demand of energy for the common or general good (Künneke & Finger, 2009; Neuman, 2006; Williamson, 1998).

2.2. INTEGRATING ENGINEERING AND GOVERNANCE

In this section, we integrate engineering and governance in our theoretical framework, primarily based on Scholten and Künneke (2016), whose four-step approach to comprehensively designing energy infrastructures framework is also described and defined, and forms the backbone of the analysis in this research.

2.2.1. SYSTEMS ENGINEERING

In addition to the institutional approach to viewing infrastructures, there is also the technical, engineering approach called 'systems engineering.' Systems engineering in this context refers to the integral design of a set of many interacting parts fulfilling particular roles, working together towards an objective or for a specific purpose (Kossiakoff et al., 2011; Waldo, 2006). The design aims to make the system perform adequately in technical terms, such as reliability, robustness, operating costs, and other technical requirements, using an iterative design process to meet these performance indicators (Scholten & Künneke, 2016). To understand when systems engineering is appropriate, Kossiakoff et al. (2011, p. 10) describe three characteristics: (1) the system is an engineered product satisfying a specified need; (2) it consists of diverse components with

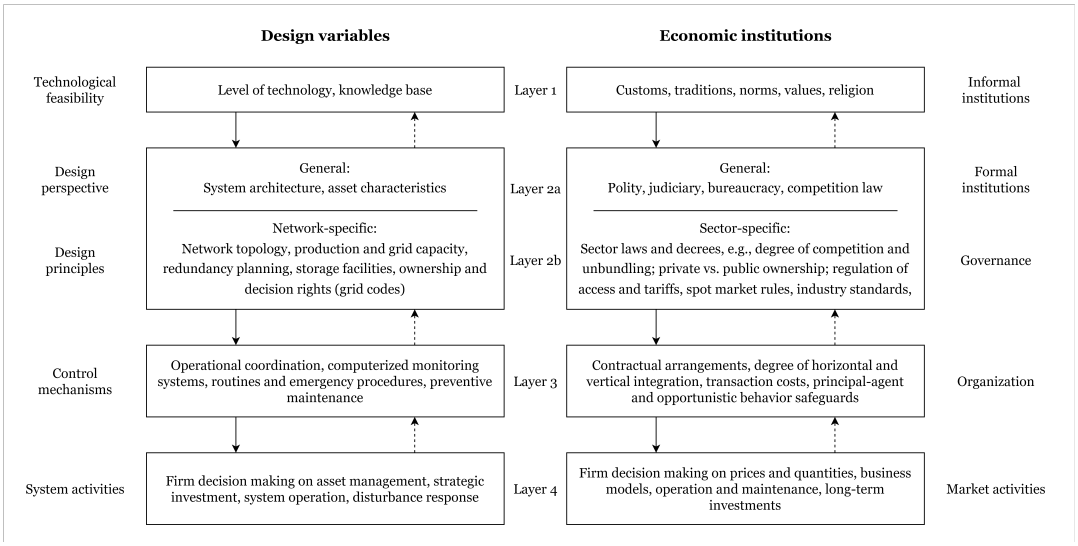

Figure 2.3: The four layers of (systems) design variables (left) and economic institutions (right) for energy infrastructures (Adapted from Scholten and Künneke (2016, pp. 10–12)).

intricate relationships, making it multidisciplinary and relatively complex; (3) it uses advanced technology central to its primary functions, involving development risk and often high cost. Comparing this to aquathermal DHN-infrastructures and the definition of energy infrastructures in this study, systems engineering is an appropriate approach to designing such infrastructures.

Scholten and Künneke (2016) distinguish between four mutually influential layers of design in the systems engineering approach, shown on the left side of Figure 2.3. The first layer refers to the technological knowledge and practical possibilities available to system designers, specific to the time and place of designing, and is not the subject of purposeful design. The second layer concerns the design of an energy infrastructure, focusing on system architecture and asset characteristics. This includes choices between an open or closed system, centralized or decentralized, and selecting technologies for energy production, transport, storage, and utilization. Designers focus on ensuring system robustness and resilience through design choices. For AE systems in this study, this involves decisions on the number of connected homes and buildings, the temperature of the delivered heat, heating methods, and thermal energy storage integration.

The third layer focuses on control mechanisms to ensure reliable operations, coordinating energy production and flow in the network through monitoring systems, emergency procedures, and backstops. The fourth layer focuses on firm decision-making to ensure robustness and reliability in daily operations, encompassing asset management, strategic investment, system operation, and disturbance response to maintain continuous operations despite potential outages (Scholten & Künneke, 2016).

As shown in Figure 2.3, the layers of systems design have counterparts on the institutional side, reminiscent of Williamson's 1998 four-layer model for institutional analysis.

2.2.2. THE COMPREHENSIVE DESIGN FRAMEWORK

While the technical design of an infrastructure is crucial for its physical operation, energy infrastructures have increasingly come to be viewed increasingly as complex socio-technical systems, and the energy transition as a socio-technical process (Bolton & Foxon, 2015; Scholten & Künneke, 2016; Weijnen & Correljé, 2021). Therefore, in addition to requiring a technical systems engineering approach for the design of energy infrastructures, the application of an institutional lens is becoming equally essential for the analysis and/or design of energy infrastructures (Andrews-Speed, 2016). Filling the need for a framework that integrates these two

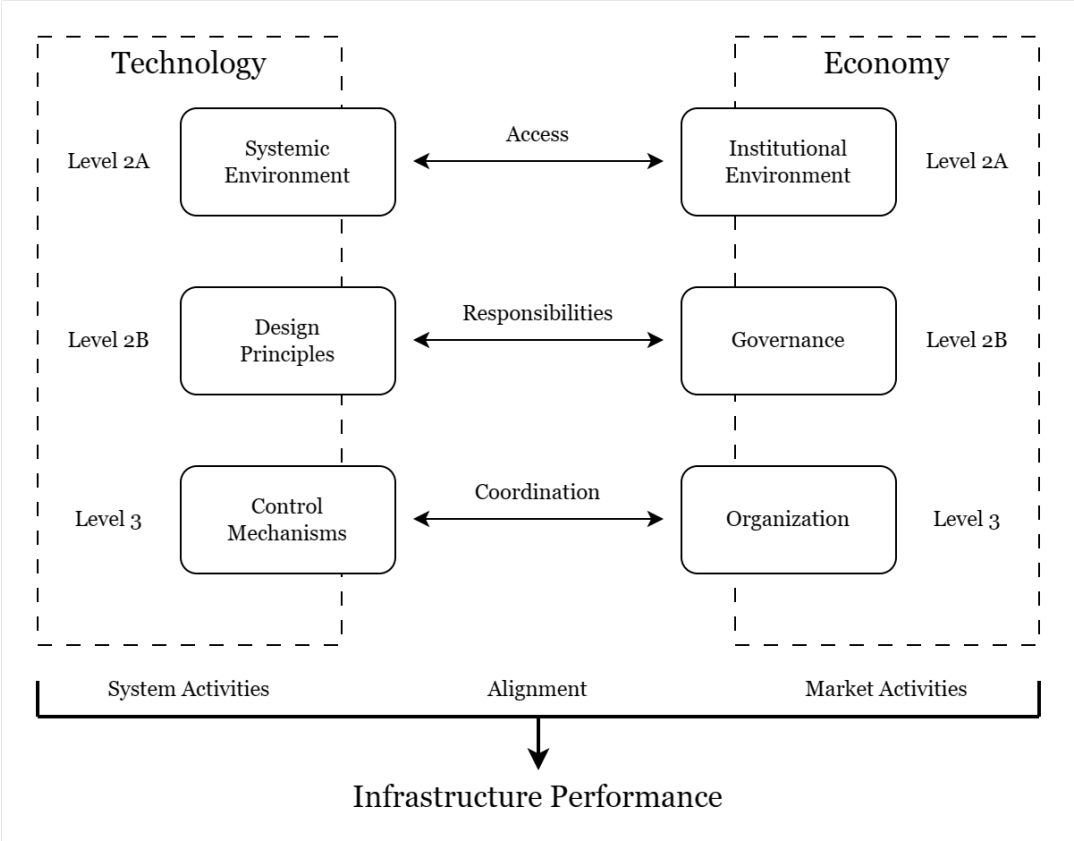

Figure 2.4: Alignment of technical and institutional designs in energy infrastructures (Scholten and Künneke (2016, p. 14), originally adapted from Künneke and Finger (2009, p. 9))

approaches, Scholten and Künneke (2016) propose the 'Comprehensive Design of Energy Infrastructures' framework, which emphasizes the need to integrate technical and economic dimensions to ensure consistency and effectiveness. This involves aligning responsibilities and decision rights across both dimensions to harmonize system and market aspects, aiming to ensure operational reliability and socio-economic efficiency in infrastructure development. This alignment has to take place on the second (2A and 2B) and third layer of the four layer model, as is shown in Figure 2.4.

Alignment on layer 2A is called 'access' and differentiates open and closed systems, both technically and economically. Technically, closed access systems are restricted to specific entities providing services under centralized control, while open access allows any capable actor to contribute to the infrastructure. Economically, closed systems are state-controlled and monopolistic, with infrastructure heavily regulated and managed through central planning. Open systems, conversely, are competitive and dynamic, driven by market forces where private companies compete for profit. Aligning these means matching open systems with market-driven policies, while closed systems align with centralized, state-led strategies.

On layer 2B, alignment is concerned with 'responsibilities' and refers to how control and authority over technical operations and market transactions are assigned within a given context. This involves determining which parties manage assets, make infrastructure investments, and respond to emergencies. Economically, these rights are allocated to promote competition and ensure efficient and effective service delivery in line with public duties. Even after market liberalization, networks often remain monopolized due to their strategic importance, whereas other sectors are opened to competition. The design process needs to balance these responsibilities to maintain market functionality and competitive opportunities.

Alignment on the third level, 'coordination', refers to the interactions between different actors involved in

producing goods or services within a set environment. It ranges from centralized to decentralized management, depending on the diversity and interdependence of the organizational units. Economically, it encompasses selecting appropriate transactional relationships and organizational structures, such as spot markets or vertically integrated firms. The design process should ensure that the coordination method does not obstruct communication or efficiency, implying that centralized systems may pair well with vertical integration, while decentralized structures could complement private contracting.

2.2.3. THE FOUR-STEP APPROACH

In their comprehensive design of energy infrastructures-framework, Scholten and Künneke (2016) define four steps to follow in order to effectively utilize their framework and come to comprehensive and suitable designs. These steps are:

1. *Description of the Specific Energy Sector.* This step involves providing a detailed overview of the existing energy sector, including its systemic and institutional environment, performance criteria, technologies in use, operational practices, key actors, market governance and organization practices.

2. *Identification of Changes.* This involves detailing the specific techno-operational or economic-institutional changes under investigation, such as the introduction of new technologies, services, or organizational forms. It describes where these changes occur within the existing framework, what new elements are added, and what existing elements might be replaced.

3. *Interpretation of Implications.* Focusing on assessing the operational and market implications of the changes introduced. This includes examining how these changes affect other layers of the system, the roles and responsibilities of various actors, and the need for adjustments in market organization and governance.

4. *Investigation of Design Options.* The final step involves exploring potential design options to address the implications highlighted in the previous step. This includes analyzing performance trade-offs and considering how design principles, control mechanisms, governance, and organization need to be adapted to ensure the reliable and effective operation of the energy system, while meeting socio-economic criteria. Tensions between design options are identified and solutions proposed, potentially requiring a reevaluation of the existing systemic and institutional environment.

In this research, we will use this structured approach to systematically analyze the Frisian heating system, identify what changes in the context of ADHNs the region is committed to, interpret what the specific governance implications of these infrastructures are and investigate fruitful design options in the form of broad directions to further explore. In Chapter 3, we describe how we utilize these steps to structure this research and answer the research questions.

2.3. GOVERNANCE ARRANGEMENTS

In this section, we operationalize the governance structures, the lack of which pose a barrier to ADHN-realization, by defining them as being governance arrangements. Furthermore, we introduce the seven elements to address in governance arrangement design by Termeer et al. (2017), which we utilize to operationalize step three of the four-step approach to comprehensively designing energy infrastructures.

2.3.1. DEFINING GOVERNANCE ARRANGEMENTS

In this study, we define governance as the societal steering of economic activities through structures that shape the process of coordination between interdependent actors to achieve common gains (Bevir, 2012; Treib et al., 2007; Williamson, 1998). To operationalize this, we define 'structures' as 'governance arrangements.' For governance arrangements we use the definition as posed by Termeer et al. (2011, p. 161) being the "specific rules, processes, and instruments that structure the interactions between public and/or private entities to realize collective goals for a specific domain or issue." Termeer et al. (2017) provide a framework of seven elements to address in the design of climate adaptation governance arrangements, which we will apply to the case of ADHNs in Fryslân.

Although ADHNs are primarily a climate mitigation measure, the four core arguments given for a specific framework for climate adaptation governance by Termeer et al. (2017) can also apply to aquathermal heating. First, Termeer et al. (2017) argue that adaptation is an 'emerging policy domain,' which also applies to ADHNs in Fryslân, due to the novelty of the technique, significant system differences from existing heating infrastructures, and the lack of governance experience (T. Hoppe et al., 2024; Van Popering-Verkerk et al., 2021). Second, the governance of climate adaptation involves multiple governance levels and policy sectors, each with its own interests and working methods that must be coordinated (Termeer et al., 2017). This is also true for ADHNs in Fryslân, due to decentralized responsibilities for the heat transition to municipalities, the multi-level nature of the energy transition, and the implications for energy, housing, water, and ecology policy sectors (T. Hoppe et al., 2024; Kleiwegt et al., 2023). The third core argument Termeer et al. (2017) highlight is the deep uncertainties associated with climate adaptation governance, stemming from the complexity of climate change impacts and responses. Similarly, ADHNs in Fryslân face substantial uncertainties regarding technological feasibility, long-term environmental impacts, and the economic viability of large-scale implementation (Jung et al., 2022; Van Popering-Verkerk et al., 2021). The fourth argument concerns the long-term horizons necessary for effective climate adaptation planning, which is equally relevant for ADHNs in Fryslân. These projects require long-term commitments and planning due to significant upfront investments, infrastructure modifications, and gradual shifts in regulatory and market structures to support sustainable heating solutions (Kleiwegt et al., 2023; Van Popering-Verkerk et al., 2021).

In addition to the overlap in arguments, T. Hoppe et al. (2024) specifically notes the possibility of applying the governance arrangements framework by Termeer et al. (2017) to AE.

2.3.2. THE SEVEN ELEMENTS

The aforementioned seven elements put forward by Termeer et al. (2017) to be addressed in designing governance arrangements are as follows;

1. *The Framing of the Problem.* Climate change's complexity involves multiple stakeholders with varying interests, leading to different perspectives. Effective framing is crucial to engage stakeholders through dynamic interactions, involving the creation of feasible narratives and solutions (*puzzling*) and determining the most influential perspectives (*powering*) (R. Hoppe, 2010). Solely focusing on the vast impacts can overwhelm stakeholders, hindering engagement and commitment (Dupuis & Knoepfel, 2013). Governance arrangements should allow for reflection and adaptability in framing to incorporate diverse perspectives and enhance participation.

2. *The Levels of Action.* Determining the right level to act has far-reaching consequences for stakeholders and their roles. Choosing a level from a technical standpoint often neglects formal decision-making processes and the importance of scale (Cash et al., 2006). A multilevel approach can govern issues

across multiple governance levels. Synchronization, where actors adjust their actions in alignment with the broader governance context, enhances mutual support (Termeer et al., 2017).

3. *The Timing of Policies.* Deciding when and in what order to act depends on available information and whether to act on existing knowledge or wait for more evidence. Incorporating robustness and flexibility into measures can prevent lock-in effects, premature decision-making regret, and unalterable outcomes from acting too late (Termeer et al., 2017).

4. *The Alignment across Sectoral Boundaries.* Projects like aquathermal heating affect multiple sectors, including ecology, housing, water management, and spatial planning. Effective operation across sectoral boundaries can be achieved by either including sectors in existing policy domains or creating a new domain. A separate domain organizes attention and support, while incorporation is more effective during decision-making, implementation, and enforcement (Uittenbroek, 2014).

5. *The Selection of Policy Instruments.* Tools to influence stakeholder choices or behavior include hierarchical, market-based, and network-based governance (Jordan et al., 2010). Hierarchical governance imposes norms through regulation, market-based governance uses economic instruments like carbon trading or subsidies, and network-based governance leverages communication, trust, and collaboration. Often, combinations of these approaches are used, or systems transition between modes during project development (Bevir, 2012).

6. *The Organization of the Science-Policy Interface.* This element involves organizing the relationship between science and policy, particularly for climate science and policy. Science's role is evolving from providing objective insights to a collaborative approach to policy analysis, emphasizing collective understanding and deliberation (R. Hoppe, 2010). Opposition to climate science and policy increasingly uses 'science-based' argumentation. Therefore, organizing the science-policy relationship to promote stakeholder collaboration is essential. This can be achieved through joint fact-finding and co-production via boundary organizations accountable to both scientific and political realms, maintaining clarity of role (Termeer et al., 2017).

7. *The Appropriate Forms of Leadership.* Leadership in climate change involves organizing systems with dispersed resources and responsibilities. Beyond traditional roles, effective leadership in climate policy requires various styles, including organizing, ideating, connecting different groups, and fostering innovation. Citizens, NGO workers, researchers, and government officials all play critical roles. This broader, more flexible leadership effectively responds to climate change challenges (Termeer et al., 2017).

In applying the four-step approach to designing infrastructures, we use these seven elements to carry out step three: interpretation of implications. These seven elements therefore act as the framework through which we analyze and interpret the implications of introducing ADHNs into the Frisian heating system on large scales.

2.4. PROTOTYPES FOR THE GOVERNANCE OF AE

In this section, we define currently existing prototypes for the governance of AE and in particular ADHNs, and explore design options for ADHN-governance arrangements based on professional literature written on the subject.

The governance of AE in The Netherlands involves navigating a landscape where the choice of system influences but does not dictate governmental roles (DWA, 2020; Van Popering-Verkerk et al., 2021). A clear

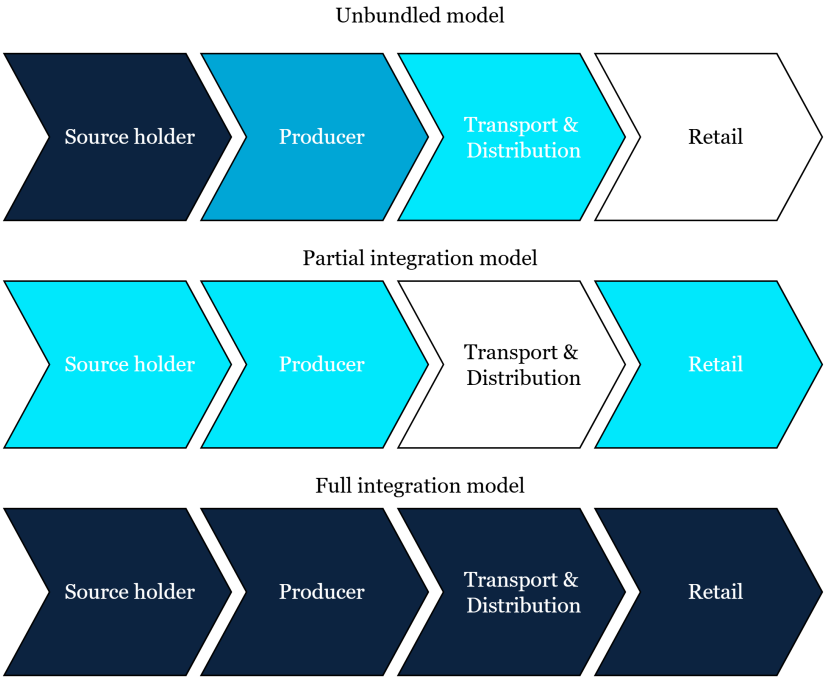

Figure 2.5: Roles in the aquathermal heating chain, if boxes are the same color in a model, those roles are integrated in that model (Adapted from Kleiwegt et al., 2023).

distinction can be made between stakeholder roles in governance arrangements for the 'chain' of aquathermal heating in the exploitation phase, and those for the process of developing aquathermal heating projects. As stated earlier, in this thesis we focus on the former. In the aquathermal heating chain, we can distinguish differing roles; *the source holder,* that owns the water source; *the producer*, responsible for extracting and producing heat; *the transporter and/or distributor*, that delivers heat through a DHN, and; *the retailer*, responsible for the actual delivery of heat and the surrounding process of facturation, administration and customer service (DWA, 2020; Kleiwegt et al., 2023; Van Popering-Verkerk et al., 2021).

For the exploitation phase, Kleiwegt et al. (2023, p. 55) describe three concrete models for the division of responsibilities in the aquathermal heating chain that we will use in this research to analyse governance arrangements. The first model concerns a fully separated heating chain (Kleiwegt et al., 2023) In this model, there is clear insight into where the unprofitable peak occurs. There are risks that one of the parties may face difficulties due to agreements on heat prices or volumes, making it important to manage these interfaces well and avoid stacking risk premiums (high transfer prices). Since each party prices its own risks and incurs its own organizational costs, this model can be relatively expensive. Tripartite agreements can be considered to keep the risks for the entire project manageable. Each part of the chain must be independently feasible or made feasible through subsidies.

The second model integrates the producer and retailer, and optionally the source holder, and separates the transporter in another actor. The transporter has its own business case and receives a fixed or variable fee. The supplier controls production costs and delivery, thereby managing all price and volume risks. Risk management is ensured from production to delivery, with minimal risk of any party being disadvantaged, unless the transporter is entirely paid through variable (volume-based) fees. This model also provides clear insight into potential unprofitable peaks (Kleiwegt et al., 2023).

The third model described by Kleiwegt et al. (2023) is a fully integrated heating company. In an integrated

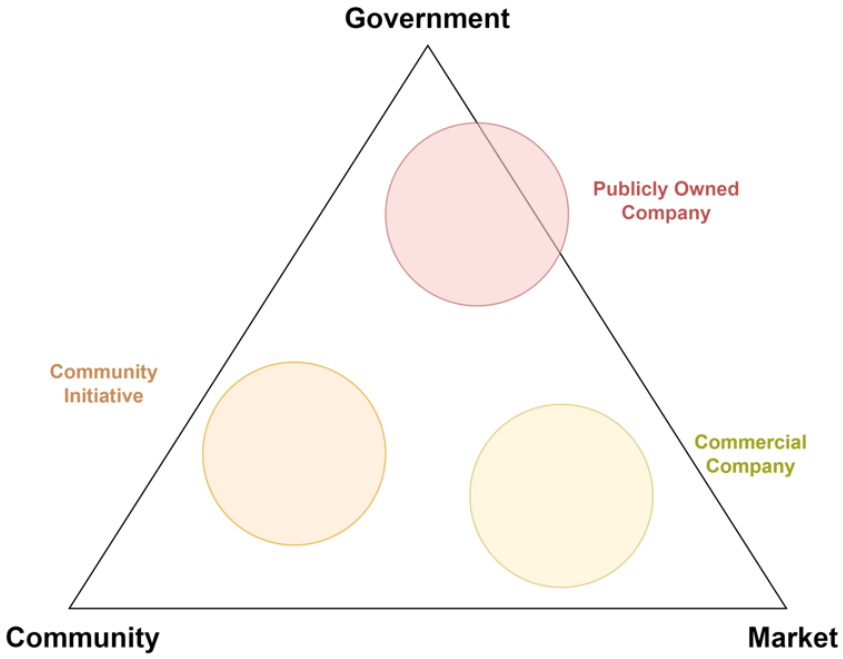

Figure 2.6: The triangle of government, market and community and the position of the three prototypes in it (Van Popering-Verkerk et al., 2021, p. 22).

heat company, cross-subsidization is possible between the less and more profitable parts of the network, eliminating the need for transfer pricing or stacked risk premiums. This model is feasible for newly developed infrastructure with dedicated heat sources and is typically used in closed heat networks where competition from sources is not possible. However, the lack of competition can be unfavorable for price formation towards consumers. A visualization of these three models is visible in Figure 2.5

In addition to the level of role integration of actors in the heating chain, the type of actor to take on a role is also crucial. Van Popering-Verkerk et al. (2021) defines three broad categories of actors to take part in the aquathermal heating chain: the public company, the commercial company, and the community initiative. The prototypes are visualised on a triangle between government, market and community in Figure 2.6. Each prototype embodies a distinct approach to managing and deploying ADHNs. However, it must be noted that these are not exhaustive, and that hybrid forms of governance are possible that would lie in between or outside the circles on the triangle (Van Popering-Verkerk et al., 2021).

Public and commercial companies operate similarly in AE projects by delivering heat effectively and efficiently. They prefer to control the entire supply chain to minimize dependencies and ensure reliable delivery. These systems are typically custom-designed with little focus on future development or adaptation to new sources and changing demands.

There are differences between public and commercial companies. Public companies have additional control mechanisms through shareholding, but strong direction from public shareholders can create tension between public and business values. Commercial companies are primarily active in new housing developments and require a solid business case for participation, earning partner trust throughout the process. Public companies without a profit motive generally have a more favorable public perception, especially in long-term monopoly situations.

Community initiatives, on the other hand, are driven by resident collectives rather than government entities (Klip & van Boxtel, 2020). For these initiatives, AE is part of a broader set of goals, including sustainability,

livability, and social cohesion. They integrate knowledge from society and often collaborate with professional partners (public or private). When community initiatives establish a heating network, they ensure resident control and provide more opportunities to integrate additional energy sources (Van Popering-Verkerk et al., 2021).

2.5. CONCLUSION

In this section, we synthesize the four sections of the theoretical framework into one theoretical approach that we use in this research.

In this study, we focus on the governance of energy infrastructures which involves the coordination of public, private, and nonprofit actors to manage physical networks that connect energy supply and demand for the common good (Künneke & Finger, 2009; Neuman, 2006; Williamson, 1998). Specifically, we will formulate a decision-making framework for governance arrangements for ADHNs in Fryslân. We define governance arrangements as "specific rules, processes, and instruments structuring interactions between entities to achieve collective goals" (Termeer et al., 2011, p. 161).

Comprehensive energy infrastructure designs include integrated engineering and market (institutional) elements, meaning governance arrangements and technical ADHN-designs should be aligned (Scholten & Künneke, 2016). Therefore, we employ the four-step approach to comprehensive energy infrastructure design consisting of; (1) describing the specific energy sector; (2) identifying changes in the sector; (3) interpreting the implications of these changes, and; (4) investigating design options (Scholten & Künneke, 2016).

To analyse and interpret the implications of introducing ADHNs in Fryslân for governance arrangements we use Termeer et al.'s (2017) seven elements to address in governance arrangements. Thus, by integrating analysis Termeer's governance arrangement-framework as step three in the comprehensive design of energy infrastructures-framework, we implement a concrete operationalization for this step.

In executing step four of the comprehensive design framework, we explore possible designs for ADHN governance arrangements. As starting point for this exploration, we use the aquathermal heating chain as described by Kleiwegt et al. (2023) and Van Popering-Verkerk et al. (2021). This consists of four distinguishable roles; *the source holder*; *the producer*, *the transporter, storer and distributor*, and; *the retailer*. Therefore, in any governance arrangement, these roles and responsibilities will have to be distributed among stakeholders. Furthermore, we use the three archetypal actors to take on these roles and responsibilities, as described by Van Popering-Verkerk et al. (2021): the *community initiative*, *the public company* and *the commercial company*.

3

METHODOLOGY

In this chapter we delineate the methodology utilized to perform the research necessary to answer the research questions. First, the exploratory research approach is discussed . Second, the data collections methods are described as well as the ethical considerations of using human research subjects. Third, the method for data processing and analysis is outlined. Fourth and finally, the approach to the design phase of the research as well as the subsequent validation of the design are presented in the last section.

3.1. RESEARCH APPROACH

In this section, we describe the research approach by giving a detailed description of the exploratory research approach as well as the application of the theoretical framework in this research and how we aim to answer the main research question.

In this research, we adopt an exploratory approach. Given that ADHNs are relatively new and not yet widely adopted, there exists a significant gap in the academic and practical understanding of its applications and the implications thereof for the governance of such infrastructures. The use of an exploratory approach is particularly suited to investigate an area or issue where little is known, with the aim of gaining insights and understanding rather than providing conclusive answers (Creswell & Creswell, 2018).

The exploratory approach is reflected in our research through the use of open-ended research questions and flexible, qualitative research methods such as semi-structured expert interviews, desk research and thematic qualitative data analysis. We thereby seek to uncover contextual insights that aid in both the academic understanding of the governance of ADHNs and the practical process of implementing governance arrangements for these infrastructures within the Province of Fryslân.

The structure of this research, visible in Figure 3.1, is based on the four-step approach of the comprehensive design of energy infrastructures framework by Scholten and Künneke (2016). In Chapter 4, we execute the first and second thep of the four-step approach, which entails describing the specific Frisian heating system and identifying the changes introduced to the system in this case (Scholten & Künneke, 2016). To do so, we use the data from desk research and the thematically coded semi-structured interview transcripts to answer the first subquestion in this chapter.

Chapter 5 concerns the third step of the four-step approach, meaning the interpretation of implications due to the introduction of ADHNs in Fryslân. We specifically utilize the governance arrangements framework by Termeer et al. (2017) to provide a structured approach to identifying and interpreting the relevant

implications of ADHNs for governance arrangements. To do so, we use the data from desk research and the thematically coded semi-structured interview transcripts to answer the second subquestion in this chapter.

In Chapter 6 we investigate design options by exploring possible design directions policymakers in Fryslân could take, thereby fulfilling the fourth step in the four-step approach to comprehensively designing energy infrastructures (Scholten & Künneke, 2016). To do so, we use the data from desk research and the thematically coded semi-structured interview transcripts to answer the third subquestion in this chapter.

In Chapter 7, we synthesize the findings out the previous chapters to formulate the deliberations and their considerations that together form the decision-making framework for the design of governance arrangements for ADHNs in Fryslân, thereby answering the main research question. In this chapter, we also describe the execution of the validation process used to assess the decision-making framework and explain how this effort led to changes in the final version of the framework.

Chapter 8 concerns a comprehensive discussion of this research, including a discussion of research results, societal and academic contributions, research limitations and recommendations for future research. Finally, in Chapter 9 we answer formulate the research conclusions and policy recommendations for governments in Fryslân and the WaterWarmth research project.

3.2. DATA COLLECTION

In this section we present the methods used for the collection of data to be utilized in this thesis. Thesis include desk research of academic and grey literature, as well as semi-structured expert interviews. Additionally, the ethical concerns of this study are discussed.

3.2.1. DESK RESEARCH

In this study, we employ desk research to collect the information necessary for this research. By desk research, we mean the study of academic literature as well as professional literature, meaning, for instance, report, policy documents or internal documentation of organizations (Guerin et al., 2018). To that end, we conducted a systematic study of academic literature which ultimately led to the literature review that can be read in Chapter 1 and the theoretical framework which is included in Chapter 2. The theoretical framework guides how empirical observations should be interpreted in the context of developing a decision-making framework for the design of governance arrangements for ADHNs in Fryslân. Furthermore, the theoretical framework structures our approach to formulating a decision-making framework (Kivunja, 2018). Additionally, we utilize professional literature, including government reports and internal documentation on heating infrastructure governance, as well as policy documents for both Frisian and external cases.

3.2.2. SEMI-STRUCTURED EXPERT INTERVIEWS

We use Semi-Structured Expert Interviews (SSEIs) to gain empirical insights into the governance of ADHN-systems, the Frisian heating system and relevant external cases, ultimately informing the formulation of decision-making framework. SSEIs are a widely used method in exploratory research, leveraging expert opinions to highlight key issues (Adams, 2015; Adeoye-Olatunde & Olenik, 2021). We conduct the SSEIs based on a set of core open-ended questions formulated in the interview guides used for Fryslân- and external interviews, visible in Appendix A. The semi-structured nature of these interviews allows for the the freedom for intuitive follow-ups, enabling in-depth exploration of complex topics (Kallio et al., 2016; Trinczek, 2009).

All interviews are conducted and transcribed in Dutch, except for the Danish participant, whose interview is in English. We use Microsoft Teams for interviews, recording them with consent, and generate transcripts through the software, which are then edited for accuracy. Participants receive a copy of their transcript. We

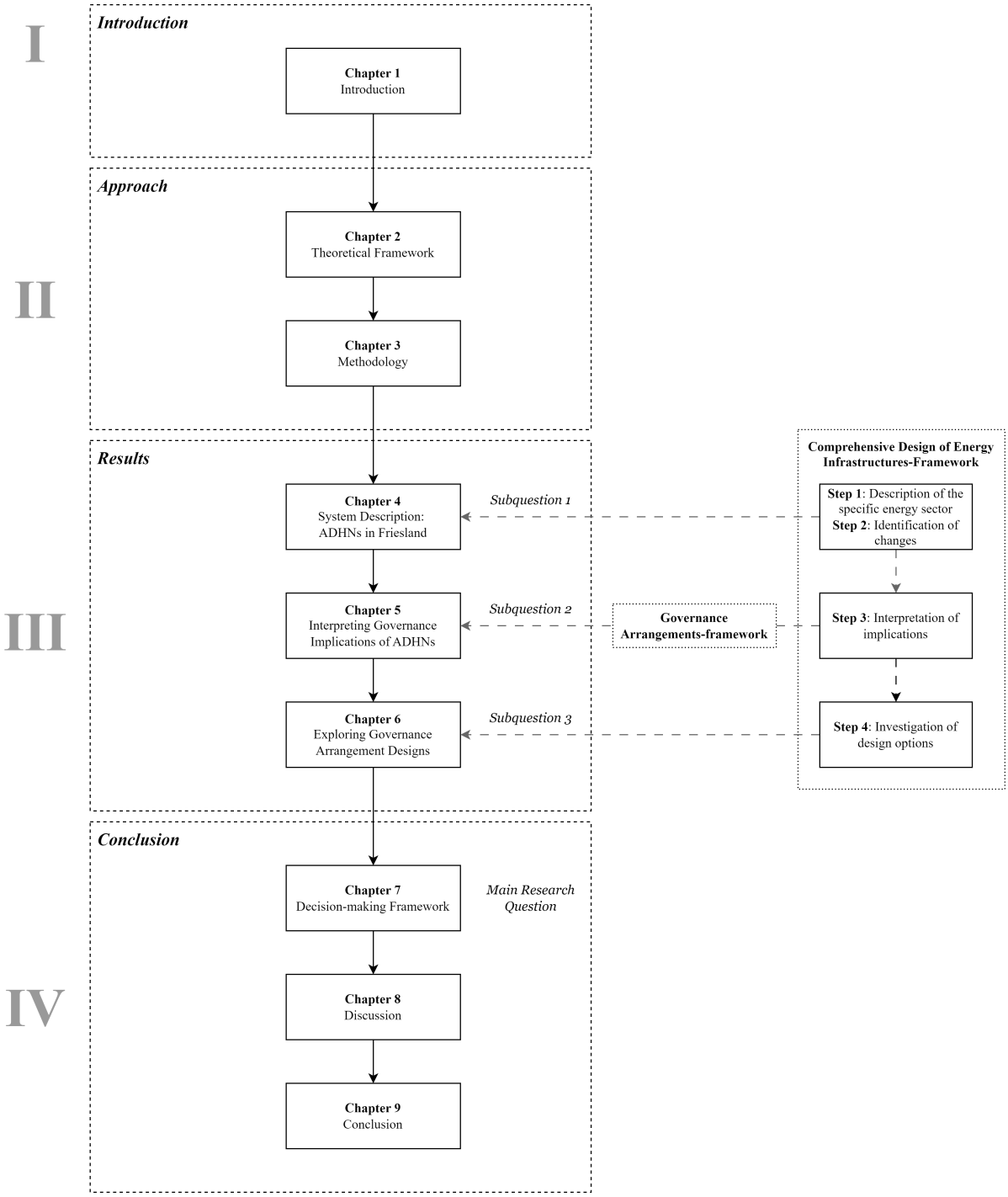

Figure 3.1: Research Flow Diagram.

identify potential participants through thesis supervisors' recommendations, previous participants' recommendations, internet searches, and relevant research authors, contacting them via email or LinkedIn.

We conducted 21 interviews for this study, each assigned a three-letter acronym listed in Table 3.1. Ten participants have a direct relationship with ADHNs in Fryslân, forming the 'Frisian case' interviews: four from the Province of Fryslân, three from Frisian municipalities, one from Fryslân's water board, one from a local advisory company, and one from a local aquathermal community initiative. Eleven 'External insights' interviews include participants from various governmental and research organizations, providing relevant external insights for the governance of ADHNs in Fryslân.

29 potential participants were contacted in the research process, of which eight were not interviewed: three did not respond, four declined due to time constraints, and one declined due to no longer being active in the AE sector. Notably, two of Fryslân's three energy communities involved with ADHNs declined due to timing issues, leaving only one participant from a Frisian energy community. Therefore, the insights from Frisian energy communities involved with ADHNs are based on a single interview, which may limit the generalizability of the viewpoint of these actors.

Table 3.1: Overview of interviews.

Nr.	Organization	Role	Scope	Acronym
1	Province of Fryslân	Project Leader Aquathermal Energy	Fryslân	PF1
2	Province of Zuid-Holland	Advisor Heat Transition	External	PSH
3	Municipality of Leeuwarden	Strategic Advisor Sustainability	Fryslân	MLE
4	Water Board Fryslân	Advisor Energy Transition	Fryslân	WBF
5	Province of Fryslân	WaterWarmth Project Coordinator	Fryslân	PF2
6	Mijnwater	N/A	External	MIW
7	Erasmus University	Researcher	External	EUR
8	Municipality of Middelfart	Head of Climate	External	MID
9	Advisory Company	Researcher and Advisor	Fryslân	ADV
10	Province of Fryslân	Team Manager Energy	Fryslân	PF3
11	Municipality of Súdwest-Fryslân	Process Manager Energy Company	Fryslân	MSF
12	Netwerk Aquathermie (formerly)	Senior Advisor (formerly)	External	NAT
13	Province of Fryslân	Project Leader Climate and Energy	Fryslân	PF4
14	Mun. of De Fryske Marren	Policy Advisor Heat Transition	Fryslân	MFM
15	Municipality of Nijmegen	Lead Heat Transition	External	MNI
16	Water Board Rijnland	Policy Advisor	External	WBR
17	Municipality of Mechelen	Advisor Heat Transition	External	MME
18	Province of Noord-Holland	Policy Advisor Heat Transition	External	PNH
19	Water Board Vallei en Veluwe	Policy Advisor	External	WBV
20	Eigen Warmte Balk	Project Leader	Fryslân	EWB
21	Province of Gelderland	Project Leader Heat	External	PGL

As a research method, the quality of SSEIs strongly depend on the interviewer's skill, the interviewee's willingness to share, and the potential subjectivity due to small sample sizes. Analyzing qualitative SSEI data also requires significant expertise and time (Adams, 2015). By acknowledging these limitations and keeping them in mind during analysis and interpretation, we aim to minimize their impact on our findings.

3.2.3. ETHICAL CONSIDERATIONS

Due to the sensitive nature of the personal information collected for the SSEIs, careful consideration of respondent privacy and data management is crucial. To conduct research responsibly, the TU Delft requires approval of a thesis research plan by the Human Research Ethics Committee (HREC). For this thesis, we obtained HREC approval through a comprehensive submission addressing privacy and ethical concerns, along with a data management plan and informed consent statement.

Data management for this thesis involves storing contact details, names, and surnames of (potential) interviewees in a password-protected Excel file on TU Delft's OneDrive servers. Interviewees are assigned a

number prior to participation, which is used to refer to their interviews in this report. The matching between interview numbers and individuals is only stored in the secure Excel file. Interview recordings and transcripts are stored in a separate OneDrive folder identifiable by the assigned number, ensuring maximum protection of interviewee privacy.

3.3. DATA ANALYSIS

In this section, we describe the method for data analysis used in this research.

The total of 21 transcripts created in this study together consist of 118.917 words, totaling 272 pages of text and an average transcript length of 5663 words. To analyse these transcripts, we employ thematic analysis, guided by our theoretical framework, and Atlas TI software to identify and analyze patterns in the SSEI transcripts (Hwang, 2008; Liamputtong, 2009; Riger & Sigurvinsdottir, 2016).

We use a combination of inductive and deductive coding. For the deductive coding, we define nine preliminary codes based on the theoretical framework: the seven elements of governance arrangements and technical- and institutional system aspects. Additionally, we employ inductive coding to generate new codes for themes and insights that emerge during the coding process.

We execute the coding process iteravely, in two cycles. In the first cycle, we identify relevant quotations and assigned codes, either inductively or deductively. This way, through a in a steady increase in the number of quotations and codes during the first cycle, we found 561 quotations and 76 different codes across all 21 transcripts.

In the second cycle, we consolidate codes into broader themes by merging inductive codes into thematic codes and eliminating irrelevant codes or quotations. Additionally, we inductively establish subcodes for five of the seven element-based codes, thereby ensuring the final coding scheme is comprehensive reflects the difference of opinions on the larger thematic codes. This process reduced the number of main codes to 23, with 24 additional specific subcodes. The resulting codes can be seen in Appendix B, in Table B.1.

To illustrate the coding process, we take the following quotation by participant PF1 as an example: "There are heat pumps that have existed for 40 years, so that is not new at all. The technology is simply market-ready. The same applies to district heating networks." This quotation was created due to the strong opinion conveyed on the maturity of ADHN technology. In coding cycle one it was assigned to the deductive *Timing of Policies*-code, based on one of Termeer et al.'s (2017) seven elements, due to the implications of the quote for whether the timing of implementing ADHNs is right. In coding cycle two, the *Timing of Policies*-code was divided into several subcodes. This quotation was put under the subcode *Maturity Technology*, which contains quotes discussing whether ADHNs are technologically ready for implementation. Broadly, this cycle-based method was applied to all transcripts and quotations.

3.4. DECISION-MAKING FRAMEWORK AND VALIDATION

In this section, we delineate the method through which the decision-making framework is formulated and validated.

Based on the results of this study, we formulate a decision-making framework for the design of governance arrangements for ADHNs in Fryslân. By decision-making framework we mean an entity that clarifies what decisions have to be made, and what deliberations should influence those decisions (VNG, 2020). The decision-making framework is based the four step approach to comprehensively designing energy infrastructures, meaning deliberations and considerations are divided into three distinct steps (Scholten & Künneke, 2016). We omit the first step of the comprehensive design framework due to its focus on a more general description of the Frisian heating system, lacking decision-making points.

The deliberations and considerations we formulate will facilitate the clarification of intentions, making of choices between different implications in governance arrangements, the alignment of solution spaces and the identification of further steps in the design of specific governance arrangements for ADHNs in Fryslân.

We validated the decision-making framework through an interactive workshop with the members of 'Missy Wetterwaarmte', the Frisian collective of policymakers involved in ADHNs. Eleven representatives of differing Frisian governments attended the validation workshop at the provincial government building in Leeuwarden, which was held during Missy Wetterwaarmte's bi-weekly physical meeting. Of the two hour meeting, one hour was dedicated to the validation workshop. The results of the validation workshop and the subsequent changes to the decision-making framework are described in Chapter 7.

4

System Description: ADHNs in Fryslân

In this chapter, we execute step one and two of the four-step approach to comprehensively designing energy infrastructures, based on Scholten and Künneke (2016) and as outlined in Chapter 2. This approach involves; (1) describing the specific energy sector of aquathermal heating in Fryslân and (2) identifying the changes occurring in that sector.

4.1. The Frisian Heating System

In this section, we provide an overview of the heating sector in Fryslân. We discuss the current state of the sector based on its specific technical and institutional characteristics. This sets the foundation for understanding the context in which ADHNs will be implemented.

4.1.1. Background

Fryslân is one of the twelve provinces of The Netherlands, which is the layer of government between local municipalities and the national government. It is situated in the Northern part of the country and is known for its abundant lakes and waterways, a reputation the province actively embraces (Provincie Fryslân, n.d.-a). Fryslân is the third largest Dutch province, the largest including water area, while having a relatively low population of roughly 660.000, making it the second-least densely populated province in The Netherlands, with a population density less than half of the national average (CBS, 2024). The province consists out of eighteen mostly rural municipalities, visible in Figure 4.1, among which are the four least densely populated municipalities in The Netherlands, as well as the largest municipality by area (CBS, 2024). As a successor to the Regional Energy Strategy (RES), Fryslân's water board, municipalities, and the province formed the Frisian Energy Table (FET), a regional platform aimed at stimulating the energy transition that also includes the regional Distribution System Operator (DSO) Liander and numerous civil organizations (Friese Energietafel, 2022). The FET aims to execute the strategy formulated in the RES by providing a platform for regional cooperation, coordination, and the sharing of knowledge (RES Fryslân, 2021, p. 8).

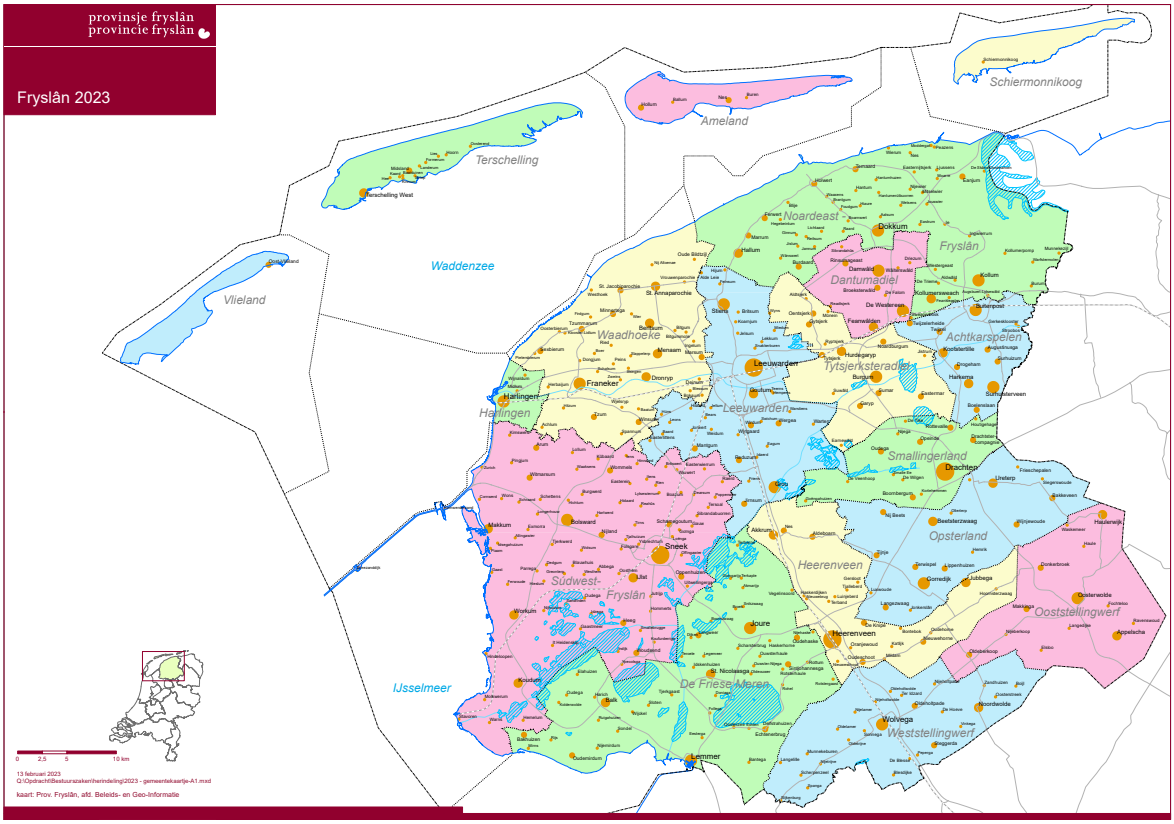

Figure 4.1: Map of Fryslân and its municipalities (Provincie Fryslân, 2023).

4.1.2. SYSTEM CHARACTERISTICS

Fryslân is a province with many small villages and very few large towns, having only five towns with more than 15.000 residents and around 400 villages (PF1; PF2; PF3; WBF; CBS, 2024). This means that most potential ADHNs in Fryslân will service "between 1500 and 1000 households" (PF1). Consequently, ADHNs in Fryslân will be different from typical Dutch collective heating systems in scale, which mostly service between 2.000 and 5.000 households (PF3).

Most homes in Fryslân are currently heated using the existing natural gas infrastructure, as are most homes in the Netherlands (Schure et al., 2022). Despite being a fossil fuel, natural gas remains a convenient and relatively cheap heating option for Frisian households (Galama, 2021). The Dutch natural gas system is unbundled: GasUnie handles transport, while regional distribution is managed by Liander, a subsidiary of Alliander. Retail services are provided by commercial energy companies like Essent, Eneco, and Vattenfall, which purchase gas from national producers such as GasTerra, trading on the international market (IEA, 2020). Notably, all actors involved in the natural gas system operate on a national or regional scale, while no municipal or local actors are involved.

Net congestion is a serious obstacle to sustainability in Fryslân (Galama, 2021; Schure et al., 2022). The current infrastructure struggles to handle increased energy demands, which impedes the development and scalability of both renewable energy projects and electricity based sustainable heating solutions, such as ADHNs (Galama et al., 2021; Van de Witte, 2023, p. 37). In addition to net congestion, Frisian participants agree that the Province of Fryslân's low tolerance of solar and wind projects further complicates the transition to sustainable (electric) heating solutions.

Fryslân is known for its distinct cultural identity, which is best exemplified by its own recognized lan-

guage, prominently displayed flag, and national anthem. Cultural institutions influence governance, making governance in Fryslân subject to different circumstances compared to the rest of The Netherlands due to its unique cultural context (Williamson, 1998). This cultural impact is particularly evident in the relationship between the provincial government and its inhabitants, who strongly identify with their Frisian heritage and thus are more receptive to initiatives from the provincial government, especially when initiatives are explicitly linked to being 'Frisian', according to most participants. Numerous participants describe this as a culturally rooted "stubbornness" and an inclination to preferring 'Frisian' projects and initiatives over those perceived as being from "The Hague" (MLE; PF1; MSF; PF2; PF4; MFM). Furthermore, the concept of 'Mienskip'—the community—is integral to Frisian society (PF3; PF4; MFM). The influence of these cultural factors on the governance of the heat transition becomes even more significant considering that both the RES Fryslan and the FET exclusively involve governments from within Fryslân, meaning little influence from other cultures of governance (WBF). The strong sense of community in Fryslân is explicitly recognized as the cornerstone of the 'Frisian method,' which is employed in developing the energy transition (RES Fryslân, 2021, p. 8). Additionally, the region's strong connection to its lakes makes aquathermal DHNs particularly well-suited to the Frisian context. This has shaped specific ambitions to become the leading 'waterwarmth-region' in the Netherlands and Europe. The cultural inclination towards collective strength, community-based initiatives, and having something uniquely 'their own', along with a profound cultural connection to water, leads three participants to describe AE as "huggable," indicating a sense of affection for the technology among Frisians (PF2; PF3; PF4).

These uniquely Frisian aspects of governance are of importance for the configuration of any governance arrangements for ADHNs in the region. In addition to this underlying cultural institutions influencing governance, the Frisian municipalities and province have also formulated the values that they want to imbed in their governance of the heat transition. These values are defined in municipalities' transition vision heat (transition) and the Regional Energy Strategy (RES). Emphasis is placed on minimizing societal costs to keep the transition affordable for all residents, particularly those with limited financial means. There is a focus on the availability and market readiness of sustainable energy technologies, ensuring that the technologies used are feasible and proven. Utilizing existing infrastructure while reducing the strain on the electricity grid is crucial, considering proximity and potential costs of expanding the grid. Community involvement is encouraged through the active support of local initiatives, recognizing the value of community-driven projects. Prioritizing solutions with the highest potential for carbon-dioxide reduction is essential, incorporating both gas-free and insulation measures. Strategic timing is also considered, capitalizing on logical moments such as relocations or renovations to reduce costs and disruption, and aligning with other municipal plans. Lastly, a collaborative approach is emphasized, working with housing corporations and other municipalities to share knowledge, save costs, and inspire broader adoption of sustainable practices. These integrated criteria should be secured in any governance arrangement in the Frisian heating transition, such as those governing ADHN-systems (Gemeente De Fryske Marren, 2022; Gemeente Leeuwarden, 2021; Gemeente Noardeast-Fryslân, 2021; Gemeente Smallingerland, 2022; Gemeente Súdwest-Fryslân, 2021; Gemeente Terschelling & Ekwadraat, 2021; RES Fryslân, 2021).

4.2. INTRODUCING ADHNS TO THE FRISIAN HEAT SECTOR

This section focuses on the changes anticipated in the Frisian heating sector in the context of ADHNs.

Building on the shared ambition of "accelerating the heat transition through the broad application of collective heating networks and aquathermia in the built environment," the Province of Fryslân, Water Board Fryslân, and four leading municipalities - Terschelling, Súdwest-Fryslân, Leeuwarden, and De Fryske Mar-

ren - have developed a collaborative program named 'Missy Wetterwaarmte,' which is Frisian for 'Mission Aquathermal Energy' (De Bruin & Hemel, 2022, p. 4). The program aims to connect 60,000 households to ADHNs by 2030, a goal that implies significant changes in Fryslân's heating system, involving the introduction of a new technology through the construction of new ADHNs. The introduction of DHNs will be particularly disruptive, as new underground infrastructures consisting of pipes will need to be constructed in existing towns.

There are an enormous amount of different possible technical configurations for ADHNs, with far-reaching implications for their governance (De Fockert et al., 2021; Fockert & Harezlak, 2022; STOWA, n.d.). Based on different definitions of ADHNs systems given in the interviews and the significant implications for their respective governance we distinguish two seperate categories of ADHNs, visualized in Figure 4.2. Centralized ADHN systems, visible on the left, use a central aquathermal heat pump to supply a DHN with medium- to high-temperature heat (above 55 degrees Celsius) (Kleiwegt et al., 2023). A STES, almost always included in collective systems, ensures year-round efficiency (De Fockert et al., 2021). These systems can integrate industrial waste heat or other high-temperature heat sources and are suitable for all types of houses, including those with low insulation. However, they are relatively energy inefficient, requiring more electricity than decentralized systems, which could exacerbate net congestion in Fryslân. Decentralized ADHN systems, visible on the right, use low-temperature (below 30 degrees Celsius) 5GDHC networks, with decentralized aquathermal heat pumps in individual homes (Kleiwegt et al., 2023). A STES supplies low-temperature heat year-round and provides cooling during summer. These systems are more energy-efficient, which can help reduce net congestion in Fryslân. However, high individual investment costs, lack of space, and varying insulation levels limit their applicability.

The governance of centralized and decentralized ADHN systems differ significantly. In centralized systems, a heat production company must invest in a central heat pump and develop a viable business model for selling the heat generated with electricity. This requires substantial capital investment and possibly dealing with competitors in the form of waste-heat producing industrial companies. In decentralized systems, the investments shift partially to individual homeowners, who must invest in home insulation and decentralized heat pumps. In the heat chain, the governance role of producer and retailer are marginal in these systems, because there is not central production, only transport and storage. This means that an unbundled heating chain in these systems is rare and not logical. This approach also possibly requires consumer education initiatives to ensure homeowners understand the workings of the relatively counter-intuitive system.

Currently, collective heating infrastructures are not yet widely implemented in the Netherlands. However, there are significant national, regional, and local ambitions to adopt these systems on a large scale to make heating in the Netherlands sustainable as part of the broader energy transition (Rijksoverheid, 2019b). The Frisian ambition for ADHNs exemplifies this shift towards collective heating systems and away from natural gas. Unlike the centralized national natural gas infrastructure, ADHNs are more decentralized and are implemented and governed at regional or local levels (DWA, 2020)

This transition from natural gas to ADHNs requires local governments to take on new roles in the heating sector. Consequently, new governance arrangements must be designed to define the roles of the respective stakeholders (Kleiwegt et al., 2023; Rijksoverheid, 2019a). In the Dutch Climate Accord, municipalities have been assigned a central and directive role in implementing the heat transition. This marks a significant shift from the previously centralized approach, which utilized the national natural gas infrastructure governed on a national scale by GasUnie and Gasterra (Rijksoverheid, 2019b).

The impending enactment of the Collective Heating Law (Wet Collectieve Warmte, or WCW) signals a potentially transformative shift in the regulatory landscape governing collective heating infrastructures, including ADHNs. This legislative overhaul is expected to redefine the rules and regulations surrounding col-

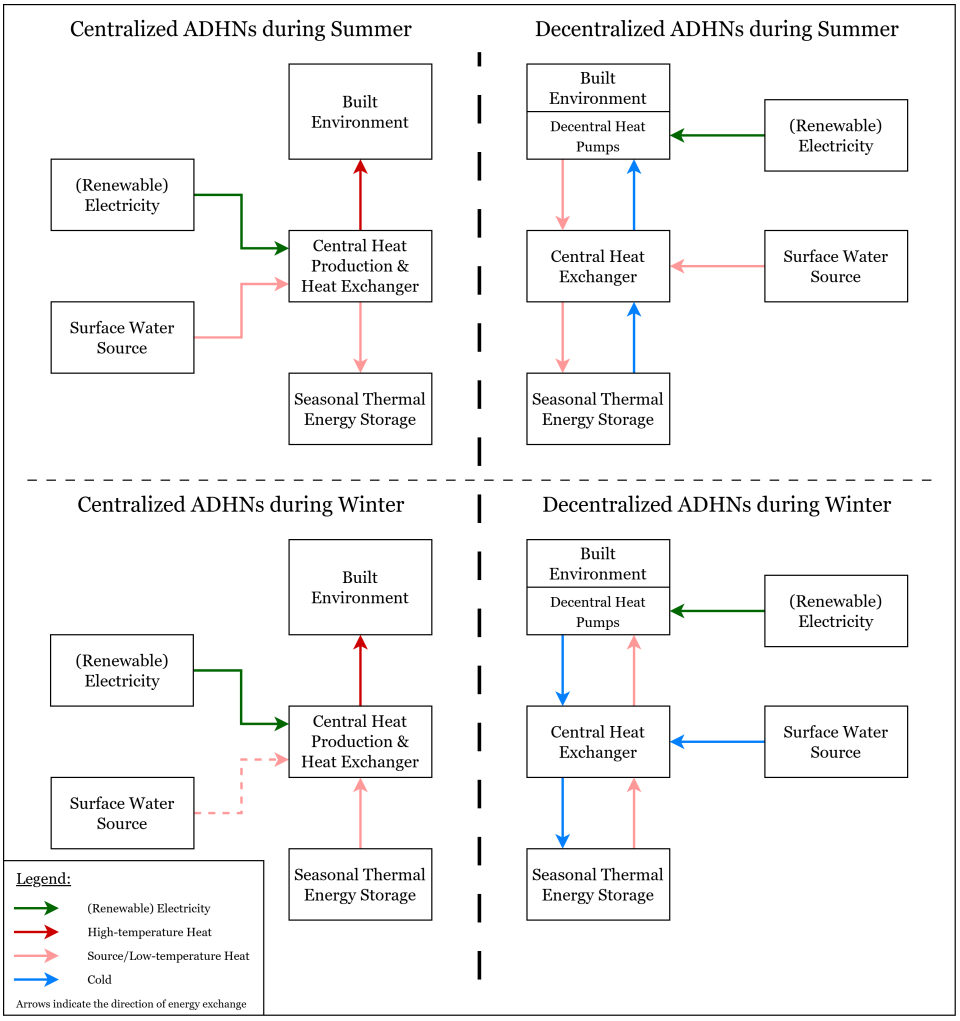

Figure 4.2: Schematic representation of the two categories of ADHNs during Summer and Winter. The categories and their specifications are based on the descriptions given by participants of the interviews in Fryslân. Please note that this is a simplified representation.

Table 4.1: Stakeholders involved in the development phase of ADHNs in Fryslân.

Stakeholder	Role	Interest
Province of Fryslân	Issuer of permits for ATES systems, potential initiator of regional governance.	Achieve provincial climate and energy goals.
Water Board Fryslân	Issuer of permits for AE installations.	Carry out societal role by facilitating the heat transition.
Municipality	Director of the heat transition, owner of municipal land, assign neighborhoods for ADHN development.	Achieve municipal goals in the heat transition.
Community Iniatiave	Instigator of ADHN-project in most cases.	Achieve sustainable heating supply in community
Heating Company (integrated or unbundled)	Realizing necessary investments and developing ADHN-infrastructure. Public or private ownership.	Achieve ADHN-based heat supply in a financially feasible manner.
Consumers / Residents	Sign up as customers for potential ADHN development.	Reliable, cheap, and sustainable heat supply.
Housing Cooperative	Transition housing portfolio to sustainable heating solutions, such as ADHNs.	Achieve reliable, cheap, and sustainable heat supply for residents.
Contractor / Advisor / Technicians	Develop the ADHN-project.	Offer services at market price.

lective heating systems (Ministerie van EZK, 2023a; NPLW, n.d.). In Fryslân, local governments are already anticipating these changes. However, the current ambiguity, as the law is not yet finalized or enacted, poses challenges for these governments in formulating definitive strategies for managing collective heating systems such as ADHNs. The WCW introduces significant changes to the governance and operation of collective heating systems in the Netherlands. Firstly, it grants municipalities substantial control over the heat transition within their jurisdictions by allowing them to designate specific areas called "warmtekavels." Within these zones, only authorized heat companies can operate, ensuring a coordinated and efficient approach to developing and managing collective heating systems (Ministerie van EZK, 2023b). Secondly, the WCW mandates that these heat companies must be more than 50% publicly owned, ensuring that the operation and benefits of collective heating systems remain under public control. This measure enhances accountability and ensures alignment with public interests (Ministerie van EZK, 2023b; NPLW, n.d.). Thirdly, the WCW reforms the current tariff system, moving away from prices linked to natural gas costs to a cost-based tariff system. This change aims to make heating costs more transparent and reflective of the actual expenses incurred by heat suppliers, providing better protection for consumers against excessive tariffs (Ministerie van EZK, 2023b).

During the development of ADHNs in Fryslân, a number of critical stakeholders are always involved. These stakeholders are listed in Table 4.1, based on descriptions by participants and the stakeholder analysis by Kleiwegt et al. (2023). It is important to note that these stakeholders are only for the development phase. In Chapter 6, we will discuss in more detail the critical and potential actors who will fulfill roles in the aquathermal heating chain during the exploitation phase.

Consequently, due to the introduction of these new collective aquathermal systems and the new central role for municipalities in heating, new governance arrangements will have to be developed that account for the new roles of municipalities, the Frisian institutional context, and the technical characteristics of ADHNs. The implications of these changes for governance arrangements in Fryslân will be interpreted in Chapter 5 by addressing the seven elements by Termeer et al. (2017). Furthermore, we must explore which actors can assume roles in governance arrangements for the exploitation phase of ADHNs, contrasting with the development phase. Specifically, we will identify what actors can fulfill roles in the integrated or unbundled heating chain, highlighting the shift in responsibilities from development to operational stages, in Chapter 6.

4.3. CONCLUSION

In this section, based on the analysis in this chapter, we answer the first subquestion of this research:

1. *What are the distinctive characteristics of the Frisian heating system, and how will the introduction of aquathermal district heating networks alter this system?*

The Frisian heating system is characterized by its rural setting with many small villages and only a few larger towns. The province has a low population density and relies heavily on natural gas for heating, utilizing the existing infrastructure managed by national and regional entities, without active involvement of municipal actors. Additionally, Fryslân faces net congestion issues that impede the development and scalability of renewable energy projects as well as the large-scale adaption of individual air-based heat pumps. The region also has a unique cultural identity, with a strong sense of community ('Mienskip') and a preference for local initiatives. Frisian government have stated ambitious goals for the realization of ADHNs, based on Fryslân's abundant lakes and waterways and the regional identify connecting Frisians emotionally and culturally to these surface water areas.

The introduction of ADHNs will bring significant changes to Fryslân's heating system. New, decentralized heating technology will be introduced, necessitating the construction of collective underground infrastructure. Governance will shift to regional and local levels, with municipalities taking on central, directive roles in the heating transition as mandated by national legislation. Two types of ADHN systems are considered for large-scale implementation in Fryslân: decentralized and centralized ADHNs, based on where heat production takes place. Centralized ADHNs require all roles in the aquathermal heating chain to be filled, either by an integrated heating company or by different actors in an unbundled model. Decentralized ADHNs, due to the decentralization of heating to individual aquathermal heat pumps in households, typically only include one integrated actor responsible for transport and storage, as retail and production play a marginal role in these models.

5

Interpreting The Governance Implications of ADHNs

In this chapter, we undertake step three of the four-step approach to comprehensively designing energy infrastructures. Specifically, we analyze and interpret the implications that follow from the identified changes to the Frisian heating system and its governance arrangements due to the introduction of ADHNs. This analysis utilizes Termeer et al.'s (2017) seven elements to address in governance arrangements. The exact definition and usage of each element, as employed in this chapter, are detailed in Chapter 2. Our analysis and interpretation are based on the results from the SSEIs and thematic coding, as well as relevant professional literature. To accurately interpret the implications of the seven elements in the Frisian case, we compare and contrast themes and quotations from participants related to both the Fryslân scope and the external scope.

5.1. The Framing of the Problem

In this section, we explore the public's and policymakers' mixed views on ADHNs as well as potential positive frames in the Frisian context, to enhance its acceptance.

A predominant existing frame noted by both Frisian and external participants, posing a significant risk to the crucially important participation rates of residents, is the association of (A)DHNs with high heating costs, or at least the risk thereof. This perception is largely attributed to numerous national news stories in recent years that have highlighted extremely high heating costs experienced by individuals connected to DHNs. A participant from the Province of Fryslân referred to these reports as "horror stories," noting their significant negative impact on residents' confidence in ADHN projects and their willingness to participate (PF2). If the initial ADHNs in Fryslân result in higher costs for residents than initially estimated, the negative impact on confidence and participation rates could escalate. This risk is further exacerbated by a participant's observation that unrealistic expectations are being created by explicitly framing ADHN projects as a cost-saving alternative for residents currently using gas, in an effort to entice them to join the collective (WBF). This is particularly concerning because ADHNs require the vast majority of local homes to connect in order to be financially viable . Lower connection rates could lead to higher costs, potentially creating a vicious cycle of increasing expenses and decreasing participation.

Another risk is the mismatch identified by numerous participants between the physical reality of the Frisian electricity system and the current framing of ADHNs as an alternative to renewable electricity pro-

duction. They describe this framing, which positions ADHNs as a hassle-free substitute for solar panels and wind turbines, as problematic. One participant highlights the challenge of countering this narrative, primarily driven by politicians, though another notes that it is starting to subside (MFM; PF4). Participants link ADHNs to the necessity for increased renewable electricity production, but observe that connection being insufficiently made in the political framing of ADHNs (PF4; MLE; MFM). There is a specific dislike of wind turbines in Fryslân that participants identify as culturally rooted, resulting in harsher restrictions on renewable energy production then elsewhere in The Netherlands, according to participants. This false framing is problematic because it misleads the public and policymakers about the actual requirements and implications of implementing ADHNs, potentially undermining efforts toward sustainable energy solutions. Therefore it has to be addressed going forward.

A potential frame that could contribute to the acceptance of ADHNs in the Frisian context, is the framing of ADHNs as uniquely 'Frisian' projects. This is due to a few reasons. First, ADHNs pose an opportunity for local and/or regional economical development, by involving local businesses in the infrastructure's development, operation, and maintenance (PSH; NAT; PF3). Additionally, incorporating public or community-based ownership of ADHNs allows profits and wealth generated by the heating system to flow back into local communities (MID; PF4). These aspects can be used to frame ADHNs positively towards residents, i.e. potential clients. The second reasons, more specifically true for Fryslân, concerns framing ADHN's as 'Frisian infrastructures', perhaps ran by Frisian public companies. This potential emontional and cultural link between the Frisian cultural identify and ADHN-infrastructures is recognized by all participants from Fryslân. One participant noted, "if we run our own company, a Frisian company, that helps a lot" (PF1), while another argued that founding a Frisian heating company would be appeal to "the Frisian identity", and would therefore be "logical" (PF2). This aligns with the earlier mentioned "huggable" nature of AE. Positively framing ADHNs by associating them with local identity elements, such as 'Mienskip,' the relationship with lakes, and the Frisian identity of involved parties, could stimulate resident support and participation in ADHNs, making them more viable.

5.2. THE LEVELS OF ACTION

In this section we discuss the right distribution of governance roles between different levels of action, and what opportunities and risks this might entail. To that end, we discuss acting on the following levels; local community initiatives; the municipalities, the water board, the province and the national government.

The local initiative is recognized as a crucial element in developing ADHNs in Fryslân, as noted in interviews, the RES, and municipal policy documents (Gemeente Leeuwarden, 2021; Gemeente Noardeast-Fryslân, 2021; Gemeente Súdwest-Fryslân, 2021; RES Fryslân, 2021). While rooted in Frisian culture, concerns arise over the professionalism and organizational skills of community initiatives (PF1, MFM). Additionally, not all towns can start such initiatives, risking insufficient action in the heat transition (PF3). A bottom-up approach may also misalign with optimal larger-scale outcomes. Balancing standardization with community inclusion is essential for effective governance of ADHNs in Fryslân.

The directive role of municipalities in the heat transition is considered the most logical level of governance for ADHNs by Frisian participants. One participant attributes this to municipalities' existing responsibilities for infrastructures like roads and sewage (MSF). However, almost all participants note significant challenges, as municipalities often lack the necessary resources—personnel, funding, and expertise—to efficiently implement the heat transition and manage ADHNs. In Fryslân, the participant from the municipality furthest along with ADHNs is most optimistic about municipal capabilities (MSF). Many Frisian participants discuss the possibility of municipally-owned public heating companies, perhaps fully integrated. Notably, external

participants are more pessimistic about municipalities' capabilities and dismiss the idea of a fully municipal integrated heating company, citing lack of funds, manpower and commercial experience as the major inhibitors to municipal public heating companies.

Water boards play a legally appointed role in safeguarding water quality and issuing extraction permits for AE (PF1; WBR; WBV). However, water boards can also go beyond this purely legal role, to play a "societal role" (WBV; WBR). Water Board Fryslân executes its societal role by ensuring "the largest group possible profits from what we make available" (WBF). This philosophy has driven them to actively participate in the Missy Wetterwaarmte initiative, aiming to maximize community benefits and support sustainable development across the region, demonstrating its commitment to broader environmental and social goals beyond its statutory responsibilities (WBF).

Any governance arrangement for Fryslân must consider the significant role of the province. The province is well-suited for regional integration of technical choices, ensuring harmonized infrastructure and technology decisions across municipalities (PNH; PSH). Scaling up governance to the provincial level can achieve economies of scale. Furthermore, the province can lobby the national government for support and funding more effectively than local actors (ADV; MSF; PF3). It can also facilitate knowledge sharing and best practices among local parties (PF1; PF2) and manage access to surface water heating resources during scarcity (EUR). Due to the local culture of governance, the province of Fryslân may be more inclined to take a leading role in governance (PF2). Participants discuss a potential province-wide governance arrangement for ADHNs, such as a provincial public heating company. However, there is a lack of clarity and coordination, with provincial participants exploring this option while municipal participants express willingness to see it implemented (PF1; PF2; PF3; PF4; MFM; MLE; WBF). Concerns arise over the province's ability to take a leading role due to its diminished financial situation as funds from the sale of NUON are depleting. Thus, the province will need to find alternative ways to lead without substantial financial resources (PF2; PF3; PF4).

While decentralizing the directive role for the heating transition to municipalities has led to capacity issues, it remains preferable to a top-down approach from the national government, which would conflict with the Frisian culture of independence from "The Hague" (PF2). Participants believe that the national government's role should be predominantly financial, as current efforts are insufficient to achieve the climate goals set for the heating transition. They emphasize the necessity for national financial support to build local capacity and provide subsidies to cover resident costs, which cannot be managed at other levels of governance due to limited funds. Municipalities often struggle with the expertise, personnel, and financial resources required for the efficient implementation of ADHNs. By increasing financial contributions, the national government could help address these gaps, allowing municipalities to focus on the practical aspects of developing and maintaining heating networks. Participants also noted that the significant financial resources required for the transition are beyond the scope of municipal budgets (MLE; PF3; ADV; PNH; MNI). This financial support is crucial for encouraging resident participation and for the realization of new infrastructures.

5.3. THE TIMING OF POLICIES

In this section, we interpret the implications of the order of actions in the ADHN policy field. Decisions depend on available information and choosing to act now or wait for more evidence.

One of the main concerns in the timing of policies is taking premature decisions with lock-in effects that lead to 'regret' (Termeer et al., 2017). Numerous participants express the necessity of developing example ADHN projects before large-scale implementation. These initial projects should serve as critical testbeds to demonstrate feasibility, identify and solve practical- and governance issues, as well as build the confidence of stakeholders and the public.

Another concern of prematurity is based on the order of actions taken, which do not align with the steps of the *Trias Energetica* (Lysen, 1996). This principle suggests reducing energy usage first before switching to renewable energy sources. There is disagreement among participants on whether ADHNs can be applied before insulation has taken place, which is currently mostly lacking in historical town centers (MSF; MFM). Some participants express that ADHNs can only be applied to well-insulated homes, while others state that an ADHN needs to be high-temperature to work in uninsulated homes (MLE; MSF; MFM). Another participant dismisses this notion, stating that you can start at any point in the *Trias Energetica* and work from there (WBF).

There are also concerns about the timing of large-scale implementation of ADHNs being potentially too late. Participants have observed that residents in Fryslân have already begun individually switching to renewable heating solutions, such as purchasing individual air-based heat pumps. Every resident who buys an individual heat pump will be very unlikely to participate in a ADHN, leading to lower participation rates, in turn hurting ADHN business cases. This underscores the urgency for timely intervention and especially a need for clear communication and designation of what (collective) heating solution residents can expect in their neighbourhood in the coming years.

5.4. THE ALIGNMENT ACROSS SECTORAL BOUNDARIES

In this section, we examine how ADHN policies align with policies in other sectors, both within the same government and between different governments, and whether they support or conflict with each other.

The clear majority of participants from Fryslân indicate that in the alignment across sectoral boundaries there is ample room for improvement in current conditions, for instance in regards to water management, spatial planning, housing, (renewable) electricity and ecology. Especially for (renewable) electricity and housing participants express a need for more alignment with the aquathermal ambitions. In the electricity- and renewables sector, participants identify a mismatch between developing ADHNs, which is essentially electrifying heat demand, and the strict provincial policies stifling the development of solar- and wind (MFM; PF4; MLE; WBF).

Furthermore, Fryslân has net congestion issues, that limit the availability of electricity for aquathermal projects (MLE; PF3; MSF; RES Fryslân, 2021). This lack of integrated view on the technical level is also identified for Fryslân in Galama (2021). Frisian participants also highlighted an issue with technical integrality due to Fryslân's focus on community-based initiatives in the heat transition.

The bottom-up approach often overlooks the broader heating and energy system at the municipal and provincial levels, potentially resulting in conflicting technical system choices locally. This is described as running the risk of arranging the broader system based on "coincidences" (WBF). One participant states that the alignment across sectoral borders, but also the alignment between jurisdictional borders, has improved significantly between the members of Missy Wetterwaarmte, noting specifically that the issue of water management and ecology in ADHN-development are being considered directly through this medium (PF4).

5.5. THE SELECTION OF POLICY INSTRUMENTS

In this section, we discuss the various policy instruments available for ADHN governance, assess their suitability for the Frisian context, and explore appropriate combinations of these instruments for Fryslân.

Currently, network-based governance is the most prevalent approach in the development of ADHNs in Fryslân (PF4; RES Fryslân, 2021; Schure et al., 2022). Most Frisian participants attribute this to cultural values such as collaboration between local governments, a strong culture of volunteering, and the importance of 'Mienskip' (community) in Fryslân. ADHNs are currently being developed almost exclusively through collab-

oration or local community initiatives, indicating a strong network-based approach (MFM; PF4; PF1). The Missy Wetterwaarmte program, which involves collaboration among multiple Frisian governments, further underscores the prevalence of this approach. While Frisian participants are overall quite positive on this approach to ADH-governance, especially in the development phase, while opting for a combined network-hierarchical approach in the exploitation phase.

Overall, participants from Fryslân view hierarchical instruments as unsuited for the Frisian cultural context due to the regional commitment to bottom-up, collaborative approaches, which they see as opposite to hierarchical, top-down measures (PF3; PF4; MFM; RES Fryslân, 2021). However, many Frisian participants express strong support for establishing public heating companies at the municipal or provincial level, believing that these entities can effectively manage and operate ADHNs. They are optimistic about their ability to create a sustainable heating sector through public ownership and integrated management of heating systems. This enthusiasm for public heating companies suggests a nuanced view that, while generally favoring collaborative approaches, Frisian participants recognize the potential benefits of a structured, public-led initiative in this specific context.

In contrast, participants from outside Fryslân are much more skeptical of the public heating company approach. They doubt the capacity of municipal and provincial governments to establish and run heating companies successfully. One external participant stated, "municipalities are not at all equipped to run [heating] companies" (MIW). Another remarked about the retail role in the heating chain: "please do not let the government do that [..] commercial companies are much better at that" (EUR). Additionally, a participant from Nijmegen, a much larger municipality than any in Fryslân, expressed concern about the financial burden: "the investments in ADHNs, it's just too much for us as a municipality" (NMI). While Frisian participants are optimistic about the possibility of establishing public heating companies, external participants remain much more skeptical, even in cases involving larger and more urban municipalities.

Therefore, external participants emphasize exploring market-based instruments for the governance of ADHNs. They suggest involving existing companies as partners in ADHN operations, either as partial owners of specific roles in the heating chain or in a co-venture within an integrated heating company alongside community cooperatives and/or governments. This approach utilizes the commercial expertise of these companies while protecting public interests through public-private collaboration. Preferably, these companies can be (semi-)publicly owned. Examples suggested by participants include the local DSO (Alliander/Firan), HVC (a waste processor with waste-to-energy facilities), Eteck (a commercial heating company), and EBN (a state-owned natural gas company).

5.6. THE ORGANIZATION OF THE SCIENCE-POLICY INTERFACE

In this section, we explore how the science-policy interface necessary for efficient and effective ADHN-governance, as well as potential methods to further enhance the exchange and synergy between policymakers and scientists.

Participants identify advisory companies as crucial actors in bridging the gap between the science and technology side, and the policy implementation. However, there is also critique of the scale on which advisory companies are utilized by governments in The Netherlands in general. According to one participant, the extend to which advisory companies are used is detrimental to the heat transition due to rising costs, and it would be much more logical for governments, also in Fryslân, to incorporate the necessary scientific and technological expertise into their organizations by hiring more experts permanently, instead of through advisory companies.

In recent years, the level of knowledge within Frisian governments, including at the top levels, has sig-

nificantly increased (PF4). According to participants, this is due to the knowledge-sharing platform established both in FET and the Missy Wetterwaarmte specifically. Moreover, the European heat transition research grants have led to more scientific insights and knowledge-sharing on a European scale. Frisian participants especially notice the influence from Danish counterparts on the development of a Frisian approach to the governance of ADHNs. However, there remains a pressing need to further enhance technical knowledge among policymakers and improve communication with the public (WBF; MLE; PF1). The province has the potential to play a more substantial role in disseminating knowledge to lower levels of action (PF1). By doing so, it can ensure that advancements in technical understanding are effectively translated into practical applications and policy decisions at all levels.

5.7. THE APPROPRIATE FORMS OF LEADERSHIP

In this section, we interpret the implications of the forms of leadership observed both in the Frisian case and externally, and what the most appropriate forms of leadership might be in the future governance of ADHNs.

One participant highlighted the importance of government leadership in ensuring an integrated approach to the heating transition in Fryslân. They stressed that small-scale projects need to be aligned with larger efforts to ensure coherence and efficiency across different levels of implementation (MFM). Moreover, a lack of clear leadership in the heat transition is a risk for the taking of action (MIW). However, leadership in realizing ADHNs must also be taken by appropriate actors and cannot be taken by actors who only have a slight role or responsibility (WBV).

When asked about leadership in the ADHN dossier, two participants from the Province of Fryslân specifically highlighted the municipality of Súdwest Fryslân. They noted, "the municipality of Súdwest Fryslân plays an important role in this, and the alderman there also serves as an ambassador" (PF2). Súdwest Fryslân is described as the leading municipality in Fryslân regarding ADHN development and has the most concrete plans for governance arrangements. Thus, it is reasonable to argue that Súdwest Fryslân takes a leadership role in both organizing and ideating ADHN governance.

One participant emphasized that leadership on this subject is a joint effort, stating that "Súdwest Fryslân and the province together" are taking the lead (PF1). Participants broadly identify the province's role as more focused on connecting parties rather than direct organizing and ideating. Some participants believe the province should take a more direct role in organizing ADHN governance, advocating for the province to assume active leadership. They argue that the province has the capacity and resources to drive these initiatives more effectively and organize governance on a larger scale, allowing for economies of scale (PF1; PF2). However, there is also hesitation about the province's role. All participants from the Province emphasized that the approach should be collaborative rather than directive, ensuring that local municipalities and communities are involved and empowered (PF1; PF2; PF3; PF4).

5.8. CONCLUSION

In this section, based on the analysis in this chapter, we answer the second subquestion of this research:

2. *What are the implications of the changes to the Frisian heating system for governance arrangements?*

The changes to the Frisian heating system have significant implications for governance arrangements. Firstly, to avoid low participation rates, it is crucial to be transparent about heating costs and manage them effectively, addressing concerns associated with high heating costs. Leveraging regional identity and the economic benefits to the community can positively frame ADHNs, promoting them as uniquely 'Frisian' projects. At the community level, it is essential to ensure regional integration and assess the capabilities of local initiatives

when assigning roles, while maintaining organized participation processes. For the Frisian municipalities, there is a need to critically reassess their currently envisioned role in the aquathermal heating chain, considering their resource limitations. The introduction of ADHN could require the more active involvement of the province to achieve economies of scale and better regional integration.

Timing is also critical; definitive governance arrangements should be avoided until lessons are learned from pilot projects. However, while definitive decisions on governance arrangements must be based on the outcomes of pilot projects, clarity should be given as soon as possible to neighborhoods on where potential ADHNs will come. This to prevent premature adoption of individual solutions by residents, leading to lower participation rates down the line and more net congestion. Cross-sectoral collaboration should be fostered to create integrated policies and solutions, especially with explicit links between ADHN ambitions and provincial housing goals. The selection of policy instruments must recognize the complexity of involving communities in the exploitation phase, realistically assess the feasibility of municipal heating companies, and consider involving (semi-)commercial or existing public companies in appropriate roles.

Reducing dependency on external advisors by integrating scientific and technical expertise within governance arrangements is vital. Leadership should continue to be fostered through collaboration among local governments and communities, ensuring that the transition to aquathermal district heating networks is managed effectively and sustainably. These integrated approaches will help address the multifaceted challenges posed by the transition and support the successful implementation of ADHNs in Fryslân.

To effectively present the most significant implications of introducing ADHNs to the heating sector in Fryslân for governance arrangements and to address the second subquestion, this subsection summarizes the findings of this chapter by listing the key implications and their interpretations in Table 5.1:

Table 5.1: Overview of the crucial implications of introducing ADHNs to the Frisian heating sector, and the interpretation of these implications to be considered in designs for governance arrangements.

Element	**Implication**	**Interpretation**
The Framing of the Problem	High heating costs framing	Avoid the risk of low participation rates due to this frame by being transparent and controlling heating costs.
	The Frisian identity frame	Use regional identity and economic community benefits to promote ADHNs.
The Levels of Action	Community role	Prevent regional integration issues due to bottom-up approach, pay attention to initiative capabilities in assigning roles, and keep organizing the regular participation process.
	Municipal Role	Critically re-assess appropriate roles for municipalities in the aquathermal heating chain.
	Provincial Role	Consider increasing provincial involvement for economies of scale and regional integration.
The Timing of Policies	Premature decisions	Avoid deciding on definitive governance arrangements before learning from concrete examples in pilot projects in Fryslân.
	Overdue clarity	Communicate (potential) collective solutions in neighborhoods clearly to residents to prevent individual solution adoption.
The Alignment across Sectoral Boundaries	Alignment	Foster cross-sectoral collaboration for integrated policies and solutions, potentially through municipalities.
	Coupling with housing	Consider explicitly linking ADHN-ambitions to provincial housing ambitions.
The Selection of Policy Instruments	Network-Based Governance	Note that community involvement in exploitation may be complex.
	Hierarchical Instruments	Consider the feasibility of municipal heating companies realistically, especially financially.
	Market-Based Instruments	Including (semi-)commercial or existing public companies in appropriate roles can be an interesting option.
The Organization of the Science-Policy Interface	Internal Expertise	Reduce dependency on external advisors by integrating expertise in governance arrangements.
The Appropriate Forms of Leadership	Leading Through Collaboration	Continue fostering leading through establishing collaboration.

6

Exploring Governance Arrangement Designs

In this chapter, we implement the fourth and final step of Scholten & Künneke's (2016) four-step approach to comprehensively designing energy infrastructures. This step involves exploring potential designs for governance arrangements for ADHNs in Fryslân, through the data from interviews and policy documents.

Typically, this step would also include the exploration of possible technical designs. However, since this study focuses on formulating a decision-making framework for governance arrangements for future specific implementations of ADHNs in Fryslân rather than specifying technical designs, we will use the two broad categories of technical designs for ADHNs as outlined in Chapter 4. These categories will serve as a reference for the governance arrangement designs discussed in this chapter.

6.1. Municipal Heating Company

In this section, we describe the design direction of a municipal heating company and the conflicting opinions on such a design both inside and outside of Fryslân.

A municipal heating company is a public company, majority or fully owned by a municipality that owns and operates one ore more roles of the (aquathermal) heating chain (DWA, 2020; Kleiwegt et al., 2023). There are many different configurations of such an entity imaginable, ranging from a public-private partnership to carry out a specific role in the heating chain in order to protect the public interest, to an integrated heating company, owning and operating the full aquathermal heating chain and 100% owned by a municipality. Although their opinions on the effectiveness of a municipal heating company differ, Frisian participants overwhelmingly agree that municipally-owned heating companies are the direction that designs for governance arrangements for ADHNs are currently taking in Fryslân.

The participants from the municipalities of Leeuwarden and Súdwest-Fryslân indicate they are working on starting such an entity. Most prominently, the Municipality of Súdwest-Fryslân already has a comprehensive proposal for a governance arrangement of the aquathermal heating chain has already been proposed to the municipal council. This proposal, a schematic representation of which is visible in Figure 6.1, concerns a fully municipally-owned integrated heating company, owning and operating the production, transport, and retail of (aquathermal) heat (MSF; Gemeente Súdwest-Fryslân, 2024). This design was chosen because it ensures that "you can embed [the preferred] mechanisms—the cost-price approach, local ownership—within a

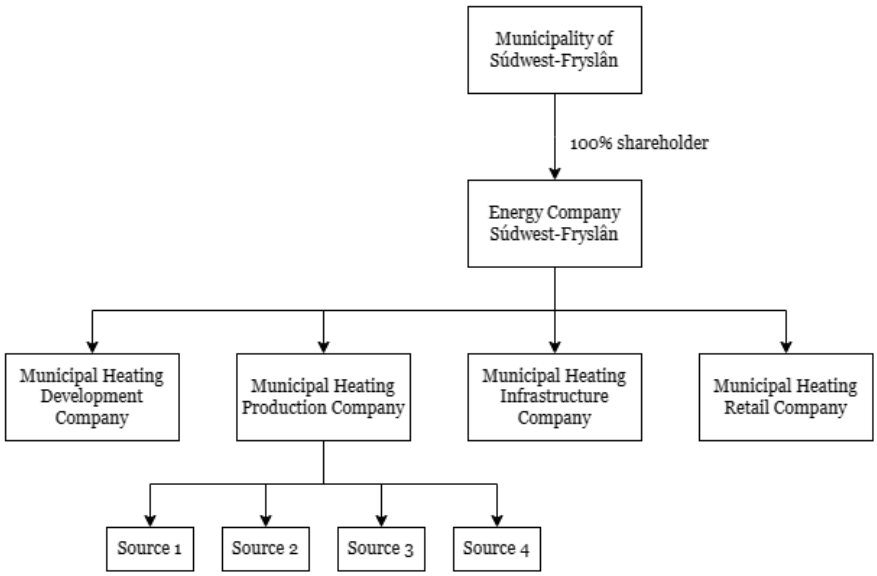

Figure 6.1: Proposed structure for a 100%-municipality owned, fully integrated public heating company in Súdwest-Fryslân (Adapted from Gemeente Súdwest-Fryslân, 2024)

municipal energy company" (MSF).

This design by the municipality of Súdwest-Fryslân is especially influential due to the leadership role on the issue of ADHN-governance that the municipality has in the eyes of participants as identified in Chapter 5. This leadership role can therefore cause the design in Súdwest-Fryslân to significantly influence designs elsewhere, which is illustrated by smaller Frisian municipalities directly saying to the municipality of Súdwest-Fryslân: "We are letting you invent the wheel, and when it is there, we can adapt that easily" (MSF). Therefore, the municipally owned integrated heating company is currently the most likely direction for governance designs for ADHNs in Fryslân.

However, some participants in Fryslân have expressed objections to this design direction. Notably, the respondent from Water Board Fryslân has voiced significant concerns about the feasibility of municipal integrated heating companies. They argue that while it might be logical for municipalities to handle transport and storage roles, assigning them other responsibilities, especially retail, is counterproductive (WBF). Furthermore, municipalities in Fryslân are already facing capacity issues due to a lack of funds and personnel. This existing problem raises concerns about who would staff the new heating companies, as municipalities cannot afford to reassign the few experts they currently have (MFM; ADV).

Moreover, participants outside Fryslân express grave concerns over this design direction. For instance, although the municipality of Nijmegen has more than twice the population of Súdwest-Fryslân and thus significantly greater financial resources, it refrained from starting a heating company on its own "due to the financial risk" (MNI). Concerns about municipal heating companies extend beyond financial risk; external participants also question the expertise, manpower, and experience that municipalities can bring to such entities (MIW; PGL; NAT). Additionally, the belief in Súdwest-Fryslân that a municipal company would result in lower costs is highly questionable. Market-based organizational forms are generally considered much more efficient in handling retail, production, and transportation roles in ADHNs (EUR).

6.2. PROVINCIAL HEATING INFRASTRUCTURE COMPANY

In this section, we describe the design direction of a provincial heating infrastructure company, which concerns both a company (partially) owned by a province or operating on a provincial scale, dedicated to a specific province.

A heating infrastructure company is part of an unbundled aquathermal heating chain, in which they own and operate the transport-, distribution- and storage infrastructure. Such an entity operates mostly as a DSO, as there is little transportation over larger distances in ADHNs (Kleiwegt et al., 2023). The term provincial refers both to the scale at which such a company operates, as well as the involvement of the Province in such an entity. As the WCW is likely to mandate majority public ownership of (A)DHN-infrastructures, any heating infrastructure company started now should be majority publicly owned, in preparation of this law.

A prominent and well-functioning example of provincial heating infrastructure company is the Gelderland Heating-Infrastructure Company (Gelders Warmte-Infra Bedrijf or GWIB). This is a public company operating on a provincial scale in the Province of Gelderland. GWIB serves as the owner and operator of district heating network (DHN) infrastructures, investing in and forming joint ventures with municipalities to establish local sustainable collective heating systems (PGL; MNI). In Gelderland, GWIB supports and stimulates municipalities in developing local and regional DHNs. Specifically, GWIB focuses on creating local public companies within the Province of Gelderland that own, operate, and maintain DHNs. Although GWIB is 1% owned directly by the Province of Gelderland, this seemingly small ownership stake is strategically structured to ensure that important decisions require stakeholder unanimity, thereby retaining crucial decision-making power within the provincial government. The other shareholders of GWIB are the regional energy investment fund, Innovation and Energy Fund Gelderland - Renewable Energy (IEG-DE), and Firan, a subsidiary of Gelderland's DSO Liander. Both IEG-DE and Firan are fully public entities. Additionally, the Province of Gelderland holds significant ownership stakes in both IEG-DE and Firan, granting it more influence than the 1% direct ownership might suggest (PGL; Alliander, n.d.). This structure allows the province to maintain substantial control over GWIB's activities while mitigating sizable direct financial risks. GWIB only participates in and develops DHNs where the relevant municipality is an active partner. To facilitate this collaboration, GWIB and the local municipality establish a Local Heating Infrastructure Company (Lokaal Warmte-Infra Bedrijf or LWIB), in which the municipality must own at least 5% of the shares. The LWIB then finds a semi-public or private company to act as the heat producer and retailer, as current legislation forbids Firan, a DSO, from being a shareholder of heat production and retail companies The diagram in Figure 6.2 illustrates this governance arrangement design.

The GWIB example provides a compelling model for active provincial leadership in the governance of ADHNs, a concept many Frisian participants have suggested should be seriously considered. A potential Frisian provincial heating company is already an object of discussion within Fryslân. Participants from Fryslân call a some form of an entity on the provincial scale "logical" (PF2) and "a good idea" (MLE), while other see it as a significant future possibility to be explored further (MSF; WBF; PF1). However, it is evident from the interviews that much is still unclear about a possible future provincial heating company. The participant from the municipality of Leeuwarden acknowledges that they have "stated out loud" their preference for this option, but nothing has happened as of yet. Participants discuss differing possibilities, without going into details and specifics for the implementation of such a 'provincial entity'. For instance, participants discuss the possibilities of a provincial heating infrastructure company (akin to GWIB) or more of an integrated provincial heating company, or a regional umbrella organization consisting of all municipal and/or local heating companies. It is clear from the interviews that the specific operationalization of a provincial heating company has not (yet) been explored in depth.

The design direction of a Frisian Heating-Infrastructure Company (Frysk Warmte-Infra Bedrijf or FWIB)

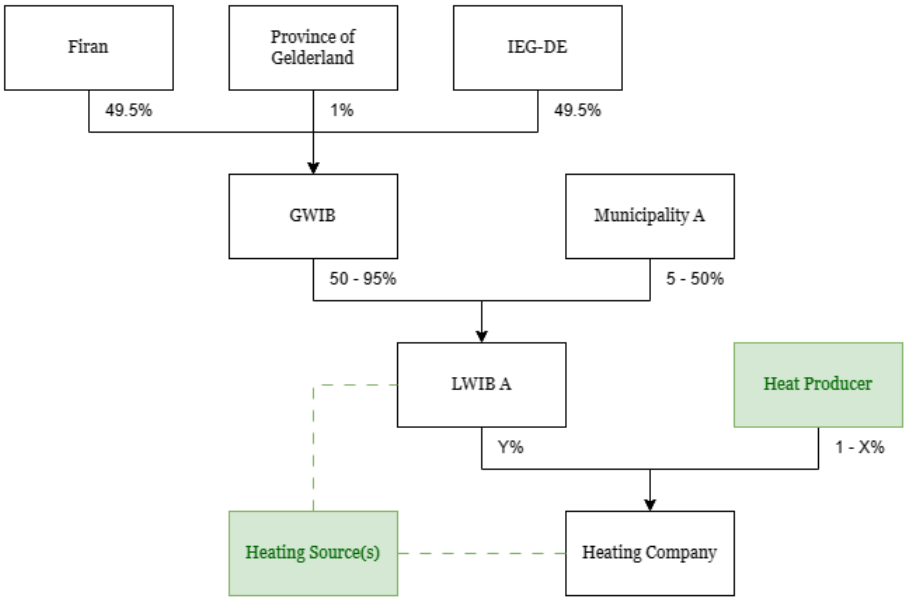

Figure 6.2: Template for DHN governance arrangements in which GWIB is an active partner. White boxes are, or are required to be, public actors, while green boxes can be public or private actors. Black arrows are shareholders, dotted green lines are contractual relationships. (Adapted from GWIB, n.d.).

could be further explored, mirroring GWIB's role in Gelderland. FWIB would invest in and form joint ventures with municipalities to develop local heating companies, which could be either integrated or unbundled depending on the local context. Furthermore, community initiatives could be incorporated into this structure, either as part of the joint ventures or by taking on unbundled roles in the heating chain. In addition to the Province of Fryslân, the existing Frisian Energy Investment Fund (Fûns Skjinne Fryske Enerzjy or FSFE) could play a significant role in owning the company and financing investments. Fryslân shares the same DSO as Gelderland, Alliander, whose subsidiary Firan could potentially be involved in FWIB. Consequently, the Province of Fryslân is also a shareholder in both FSFE and Firan, ensuring its interests should align in most cases with those of FSFE and Firan. This model's cooperative structure between a provincial public company and local (public) heating companies could effectively balance maintaining local engagement in ADHN governance with leveraging economies of scale in both technical and governance aspects. By combining local connections with broader scaling opportunities, this approach could enhance the efficiency and sustainability of heating systems across Fryslân.

6.3. COMMUNITY OWNERSHIP

In this section we discuss community ownership of ADHNs as a design direction, based on experiences with designs like this in Denmark and Fryslân.

A community ownership model for ADHNs involves significant consumer participation and ownership, typically through energy cooperatives or specifically 'heating communities' (Klip & van Boxtel, 2020). The successful implementation of such structures is exemplified in Denmark, where community-onwed DHNs have been integrated into their energy strategy for many years, providing sustainable and efficient heating to about two-thirds of homes. The Danish model is particularly relevant to Fryslân due to the similar community-oriented mindset in both regions (MID; RES Fryslân, 2021).

Danish governance of DHNs involves national, regional, and local authorities. The Danish Heat Supply

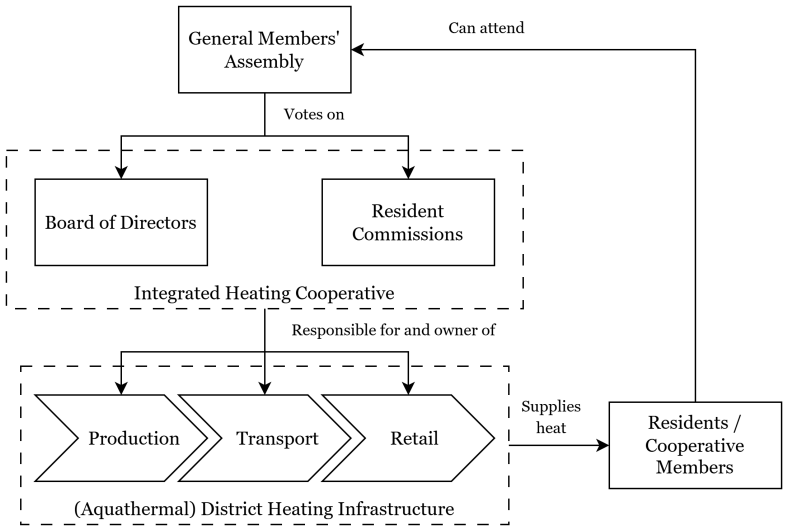

Figure 6.3: Schematic representation of an example of a Danish consumer ownership-based governance structure for an (A)DHN.

Act of 1979 mandated systematic heat planning and prioritized socio-economic heating types, contributing to their widespread adoption (Johansen & Werner, 2022). Like in Fryslân, Municipalities play a crucial role in planning and approving new DH investments, ensuring local needs are met (Vitéz & Lavrijssen, 2020). A key aspect of the Danish model is high consumer participation and ownership, often through cooperatives and municipal entities, with heat prices based on the "True-Cost" principle (Chittum & Østergaard, 2014). Consumers can purchase heat supply plants before they are sold to non-municipal entities and elect the majority of board members if they own the plant, enhancing confidence and sustainability (Vitéz & Lavrijssen, 2020).

Figure 6.3 illustrates the governance structure and operational framework of a typical integrated heating cooperative in Denmark. The General Members' Assembly, which all cooperative members can attend, votes on the Board of Directors and Resident Commissions. The integrated heating cooperative, overseen by these elected bodies, is responsible for and owns the production, transport, and retail components of the district heating infrastructure. This system supplies heat directly to the residents, who are the cooperative members and therefore partial owners of their own heat supply infrastructure.

There are multiple potential upsides to the Danish approach to the governance of ADHNs to be implemented in Fryslân. First, the scalability of the Danish approach, which allows for both upward and downward expansion, is particularly important in ensuring infrastructures meet the evolving demand of heat, specifically in rural areas (MID). Second, incorporating the community allows the economic and financial gains of ADHN-infrastructures to remain in the region and in the community (MID; PF3). By localizing ownership and letting economic benefits flow back into the community, ADHNs become "grounded in the local economy", according to the participant from Middelfart, Denmark.

Multiple Frisian participants recognize the Danish model as a valuable comparison due to its established success in developing and exploiting DHNs with- and by the community (MSF; WBF; MLE; ADV). Furthermore, the aforementioned regional economic development possibilities of the Danish approach is one of the core values of the Frisian heat transition (PF1; ADV; RES Fryslân, 2021). The community cooperative Warm Heeg provides a practical example of this model in action within Fryslân. According to a brochure by the community cooperative, the ADHN in Heeg will be operated by Warm Heeg BV, a partnership involving Cooperative Warm Heeg, Foundation Warm Heeg, the Municipality of Súdwest-Fryslân, and Kelvin BV, a commercial company. Cooperative members will have a say in key decisions, with Warm Heeg BV owning

the network and collaborating with Kelvin BV for heat delivery(Warm Heeg, 2024). This structure incorporates the three categories of governance actors in ADHNs: community, market, and government-based (Van Popering-Verkerk et al., 2021).

Notably, Heeg is located in the Municipality of Súdwest-Fryslân, and this arrangement appears to conflict with the municipality's proposed structure, highlighting potential tension between municipal interests and community initiatives, as recognized by multiple participants. Moreover, as described in Chapter 5, community ownership and initiative is at odds with regional integration of technical choices, alignment across sectoral borders and standardization, as decisions are made at the lowest level by actors who are not formally part of governments.

6.4. PUBLIC-PRIVATE PARTNERSHIPS

In this section, we explore public-private partnerships (PPPs) as a possible approach to governing ADHNs in Fryslân.

A PPP is a collaborative agreement between government entities and private sector companies to finance, build, and operate projects such as ADHNs. These partnerships utilize the expertise, efficiency, and capital of the private sector while maintaining public sector oversight and control to ensure the project aligns with public interests and goals (EUR; NAT). Specifically for ADHNs, joint ventures between public and private actors are a frequently used approach to capitalize on their respective strengths (EUR; NAT; PNH; PGL; WBF).

Figure 6.4 illustrates two possible configurations of PPPs in the aquathermal heating chain. On the left, an integrated public-private heating company is depicted, where one or more governments (municipal, provincial or national) and a private company are co-owners of a joint venture. This joint venture owns and is responsible for the entire heating chain, including sourcing, production, transport, and retail. On the right, the figure shows an unbundled approach where a public company, owned by one or more governments (municipal, provincial or national), coordinates with a private company. In this setup, the public company owns and is responsible for sourcing and production, while the private company owns and is responsible for transport and retail. The governmental body initiates a partnership with the private company because it has a legal responsibility to ensure heat supply, but wants to delegate the operational execution of the responsibilities to parties more suited to those specific tasks. In the case of commercial heat production and retailing, this could be private companies. The two entities coordinate to manage the heating chain effectively. These examples demonstrate fundamental PPP configurations, but more complex and nuanced implementations are possible, as seen in the GWIB case, depicted in Figure 6.2, where multiple (semi-)public and private companies collaborate on different levels.

Most Frisian participants express noticeable skepticism regarding the involvement of private actors in the development and operation of ADHNs. Their concerns stem from a belief that private sector involvement could prioritize profit over public welfare, potentially leading to higher costs for consumers and less focus on long-term sustainability. Participants also worry that private companies may lack commitment to local community values and might not reinvest profits into the regional economy. This apprehension is amplified by the fear that private entities might not be as transparent or accountable as public institutions, which could undermine trust and community support for ADHNs.

In contrast, there is a broad consensus among external participants that PPPs can significantly contribute to the efficient and effective establishment of ADHNs. Moreover, T. Hoppe et al. (2024) even describes the large-scale implementation of ADHNs without PPP's as "not possible" (p. 39). These stakeholders argue that PPPs harness the complementary strengths of both sectors: the private sector's innovation, efficiency, and access to capital, combined with the public sector's regulatory oversight, community focus, and long-term

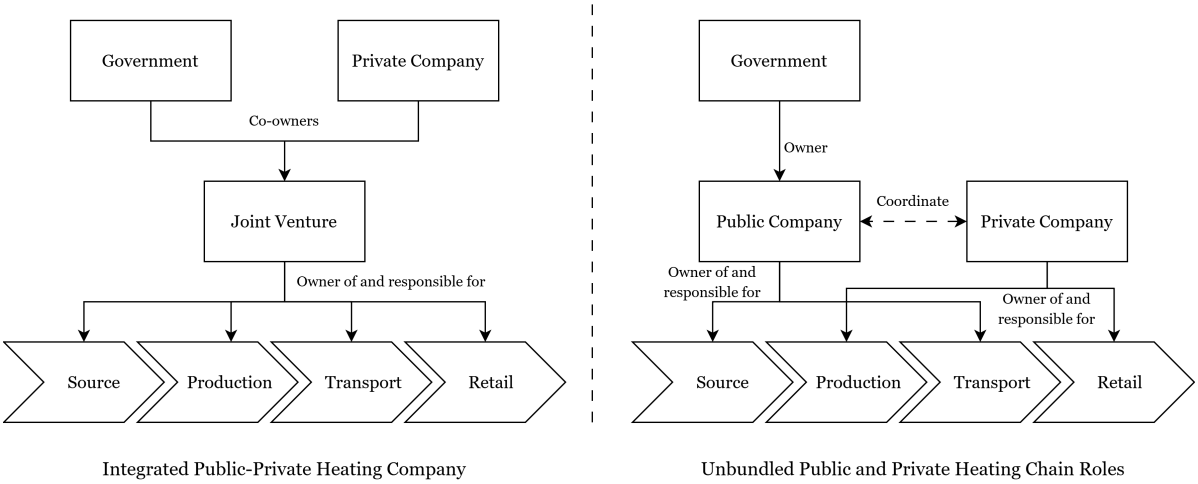

Figure 6.4: Schematic representation of conceptual examples of PPPs in the aquathermal heating chain.

commitment to public welfare. They believe that PPPs can accelerate project timelines, improve operational efficiency, and bring in advanced technologies and management practices from the private sector. Moreover, external participants highlight successful examples of PPPs in other regions, where such collaborations have led to sustainable and cost-effective district heating solutions. They suggest that, with proper regulatory frameworks and contractual agreements, PPPs can ensure that the public interest is safeguarded while benefiting from private sector efficiencies.

The discrepancy between the perceived value of PPPs in ADHN governance between participants from Fryslân and those from outside the region is significant. Frisian participants generally dismiss an approach that external experts deem essential for effective governance. This divergence highlights the importance of making informed and conscious decisions regarding the potential dismissal of PPPs. The external opinion underscores the essentiality of PPPs, suggesting that their involvement could significantly enhance the efficiency and effectiveness of ADHN projects. Therefore, it is crucial that the decision-making framework in Chapter 7 includes a thorough (re-)consideration of involving private companies in the governance of ADHNs in Fryslân. This consideration should weigh the potential benefits and address the concerns raised by local stakeholders to ensure a balanced and informed approach to governance.

6.5. PHASED GOVERNANCE ARRANGEMENTS

In this section, we explore the possible upsides of adapting differing governance arrangements for different phases that ADHN-infrastructures undergo in their development.

ADHNs have different needs in their governance in different phases between initiation, implementation, scaling and exploitation (Kleiwegt et al., 2023; Van Popering-Verkerk et al., 2021). An example of how different phases of such infrastructures can successfully be governed using different arrangements for different phases is the case of Mijnwater. Mijnwater is a Dutch company that specializes in sustainable heating and cooling solutions using geothermal energy, based in the city of Heerlen, in the province of Limburg. Mijnwater operates one of the world's first and most advanced 5GDHC networks that utilizes geothermal energy derived from the water in abandoned coal mines (Enpuls, n.d.). During its initial pioneering phase, the implementation and scale-up phase and eventually the exploitation phase, Mijnwater was governed by different actors and using different arrangements. An overview of this development is visible in Figure 6.5.

Mijnwater was founded by the municipality of Heerlen to undertake the ambitious project of utilizing

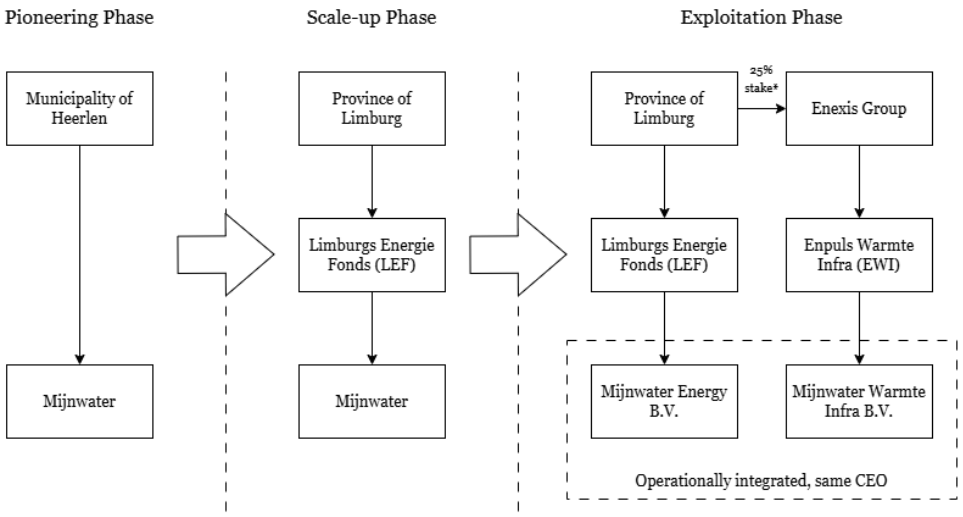

Figure 6.5: Development of Mijnwater ownership in different phases. Black arrows indicate ownership (MIW; Enpuls, n.d.). * The Province of Limburg and its municipalities together own 25% of Enexis shares.

geothermal energy from old mineshafts and a 5GDHC network to heat and cool the town. As the project progressed beyond its pioneering phase, it became clear that larger investments were necessary to scale this high-potential technology and infrastructure, which the municipality could not provide. Consequently, Mijnwater was sold to the provincial energy investment fund, Limburgs Energie Fonds (LEF). Following investments by LEF and subsequent infrastructure expansion, Dutch competition law required a separation of infrastructure ownership from the production and retail of heat. As a result, LEF sold the heat transportation and distribution infrastructure to Enpuls, a heating infrastructure company and a subsidiary of Limburg's DSO, Enexis. On paper, Mijnwater Energy (the producer and retailer) and Mijnwater Warmte Infra (the transmission and distribution system operator) are completely separate entities. However, despite the legal separation, the companies remain operationally integrated, sharing the same executive board and CEO (MIW).

This evolving ownership and structural arrangement has enabled Mijnwater to develop the first large-scale 5GDHC network in the world. This achievement was made possible, in part, by attracting the right ownership and stakeholders for each development phase of the heating infrastructure. In the current governance arrangement for the 5GDHC network in Heerlen, all aspects remain fully public. LEF is entirely owned by the Province of Limburg, while Enpuls is fully owned by the Enexis Group, a fully publicly owned DSO, of which the Province of Limburg and its municipalities collectively own a quarter of the shares (Enexis, 2023).

Although Mijnwater operates as a geothermal 5GDHC network, which may not directly compare to all ADHNs being developed in Fryslân, it shares similarities with decentralized ADHNs due to its low-temperature supply. While the heat sources for these infrastructures may differ, the governance roles of producer, transporter, and retailer remain consistent. The first significant lesson from the Mijnwater case for ADHNs in Fryslân is that different phases in the heating transition and the establishment of new heating infrastructures can benefit from varied ownership and specific governance arrangements. Secondly, as demonstrated in the GWIB case, including the regional DSO as a key actor in governance arrangements for heating infrastructures is both logical and productive. In Fryslân, the relevant DSO is Liander, a subsidiary of the publicly owned company Alliander, in which the Province of Fryslân holds a 12.65% share. Thirdly, even in the current institutional environment of national legislation concerning the division of network and production ownership, practical solutions can still lead to operational integration of the complete heating chain, as evidenced by

the Mijnwater case. Since the WCW has not yet been implemented, such a structure may prove to be a viable alternative for Fryslân. Therefore, the example of Mijnwater, and more generally the design direction of splitting governance arrangements for ADHNs into different phases with varied designs, seems a worthwhile direction for governments in Fryslân to explore further.

6.6. CONCLUSION

In this section, based on the analysis in this chapter, we answer the third subquestion of this research:

3. *What governance arrangement designs exist for aquathermal district heating networks, in- and outside of Fryslân, and what are their characteristics?*

In Fryslân, the dominant governance arrangement design direction for ADHNs focuses on municipal heating companies, with varying degrees of integration within the heating chain. Participants favor these designs due to the direct control municipalities have over costs, operations, and technical decisions. Additionally, there is an expectation of future regional or provincial governance arrangements for ADHNs, although specific concepts have yet to be developed.

A supra-municipal governance arrangement, combining regional or provincial structures with municipal heating companies, as demonstrated by the GWIB in Gelderland, presents a promising direction for policymakers in Fryslân. This hybrid approach could enhance the efficiency and sustainability of ADHNs by leveraging the strengths of both local and broader-scale governance.

However, there is a notable blind spot in Fryslân regarding the potential benefits of involving private companies in governance arrangements for ADHNs. Despite the strong rejection of private sector involvement, market-based instruments are celebrated elsewhere for their efficiency, experience, and available manpower. Frisian policymakers need to challenge this blind spot and consider how PPPs could improve societal outcomes and governance effectiveness.

Furthermore, the Frisian approach to the heating transition is largely bottom-up and community-based. Including community initiatives and energy cooperatives in formal governance roles has been challenging in the Netherlands. Policymakers in Fryslân could learn from the Danish model, where community involvement in DHN governance is standard.

Finally, there is potential in dividing governance arrangements of ADHNs into different phases of development and implementation, with differing actors and roles in each phase. This phased governance approach, successfully used by the Mijnwater company in Limburg, could be a fruitful direction for ADHN governance in Fryslân.

7

DECISION-MAKING FRAMEWORK

Governments in Fryslân are preparing for the large-scale implementation of ADHNs, exploring local, municipal, and provincial governance arrangements. This chapter outlines deliberations in the forms of questions, motivates the relevance of these questions and states the considerations that should be taken into account in deliberations and discussions. In the second section of this chapter, the validation through an interactive workshop with policymakers in Fryslân and the subsequent changes to the decision-making framework are described.

7.1. DECISION-MAKING FRAMEWORK

In this section, we formulate the decision-making framework consisting of deliberations and considerations that answers the main research question:

What deliberations and considerations should be included in a decision-making framework for designing governance arrangements of aquathermal district heating networks in Fryslân?

In Table 7.1 the decision-making framework is formulated in the form of seven deliberations in the form of open-ended questions to be addressed by policymakers in Fryslân, in order to structure the process of designing governance arrangements for ADHNs. Each deliberation in the table comes with an argumentation for its inclusion, the 'reason', and multiple considerations to weigh in addressing the deliberations.

The deliberations in the decision-making framework are divided into three steps, based on comprehensive design framework by Scholten and Künneke (2016), although the first step of the comprehensive design framework is omitted because it concerns a description of the Frisian heating sector, executed in Chapter 4.

The first step of the decision-making framework concerns defining the changes to the system that policymakers aim to achieve, based on the analysis in Chapter 4. The second step of the framework addresses the weighing of trade-offs and search for the proper balance between the governance implications of ADHNs that policymakers should seek to achieve, based on Chapter 5. Finally, the third step of the framework provides design directions for more specific governance arrangements, as explored in Chapter 6.

Therefore, the decision-making framework in Table 7.1 facilitates the design process for governance arrangements for ADHN in Fryslân, by providing policymakers with a clear and structured approach that incorporates the crucial deliberations and considerations necessary for comprehensive decision-making.

Table 7.1: Decision-making Framework

Step I: Defining System Changes	
Deliberation 1:	*To what extent should ADHNs be a goal of their own, and why?*
Reason:	In the 'Mission Waterwarmth', Frisian governments have stated the goal of connecting 60.000 homes to 'collective systems' by 2030. This raises the issue of whether ADHNs should be a goal of their own or rather a means to an end: the heat transition.
Considerations:	• Fryslân has both suitable and unsuitable socio-technical characteristics for ADHNs, meaning ADHNs are not the most cheap, efficient and/or effective sustainable heating technology everywhere in the region. • Chasing specific ADHN-connection goals can cause inefficient implementation of the technology and a limited consideration of possible techniques by decision-makers in specific cases. • Ambitious goals on ADHNs can be used to lobby national and European governments and as a means to 'get the ball rolling' on collective heating infrastructure implementation.
Deliberation 2:	*How committed are we to the ADHN-goal, and how should that be reflected in committed resources?*
Reason:	The goals of connecting 60.000 homes to ADHNs by 2030 is at risk of becoming unrealistic with the current pace of development. To retain feasibility, either the goal or the committed resources need to change.
Considerations:	• Despite aiming to become the most important AE region in The Netherlands and the ambitious ADHN-goal, ADHNs have been developed almost everywhere in the country except Fryslân. • Policymakers have to decide whether they actually want to reach this goal, or if the goal is there for reasons other than explicitly the realization of the heat transition. • To reach the goal, Frisian governments must commit to a significant scaling in the allocation of resources to ADHN-development.
Step II: Balancing Implications	
Deliberation 3:	*How can we balance integration and standardization with the bottom-up approach?*
Reason:	The bottom-up, network-based approach to ADHN-governance conflicts directly with the regional- and cross-sectoral integration and alignment of technical- and governance choices in ADHNs as well as standardization of technical- and governance practices to leverage economies of scale.
Considerations:	• Community initiatives and the network-based approach are at the forefront of Frisian governance of ADHNs, and the direct involvement of citizens is seen as crucial to the regional values. • Localized, community-based socio-technical decisions run the risk of forgoing interests on a larger scale, such as regional and across policy sectors. • Local governance arrangements mean added complexity in the regional system, as well as a need for more dedicated actors. • Standardizing of technology and governance of ADHNs is considered inevitable, but is difficult to combine with localized, community-based decision-making.
Deliberation 4:	*How can we balance the risks of acting too early versus too late?*
Reason:	In the implementation of both technical- and institutional structures for ADHNs in Fryslân, there are risk connected with both acting too early and acting too late. These risks need to be weighed and a certain balance between them needs to be chosen going forward.
Considerations:	• Frisian ADHN pilot projects have not yet been realized; acting too early would mean missing the opportunity to learn valuable lessons from these practical implementations and possibly making avoidable and costly mistakes. • The longer the delay in implementing ADHNs and providing clarity to residents, the more households will adopt individual sustainable heating which means lower future participation rates in collective solutions like ADHNs, which in turn hurts the financial viability of ADHNs.
Deliberation 5:	*How can we combine hierarchical, network-, and market-based instruments, utilizing their strengths to safeguard our values?*

Continued on the next page

Reason:	The discrepancy between Frisian and external attitudes regarding the strengths, weaknesses, and preferred combinations of policy instruments warrants a comprehensive discussion. Furthermore, the apparent rigidity of Frisian policymakers poses a risk of tunnel vision. It is crucial to use this deliberation to maintain an open mind and consider all available options.
Considerations:	• Frisian policymakers are strongly in favor of establishing public (integrated) heating companies and actively involving energy cooperatives or other community initiatives into governance arrangements for ADHNs, due to their strong preference for affordability and direct governmental control over ADHNs, which they associate with these hierarchical and network-based instruments. • Market-based instruments and actors can be highly beneficial for ADHNs, particularly in the production and retail roles within the heating chain. These strengths include greater efficiency, extensive experience, sufficient manpower, and superior financial resources, which market-based instruments can leverage more effectively than network- or hierarchical-based instruments. • Most external and some Frisian participants express concerns about excluding market-based instruments and specifically the establishment of municipal integrated heating companies for ADHNs, which currently dominates the Frisian vision for governance arrangements. • To avoid tunnel vision, it is essential to explore all possible instruments and approaches. This will enable the design of the most suitable governance arrangements by accounting for the respective strengths and weaknesses of each instrument.
Step III: Exploring Design Directions	
Deliberation 6:	*To what extent can we use different governance arrangements and actors in differing phases of ADHNs?*
Reason:	The phased approach to governance arrangements has proven effective in facilitating the development of innovative heating infrastructure from inception to scaling and exploitation. Therefore, this design direction warrants further exploration by policymakers in Fryslân.
Considerations:	• In the development and implementation phases, integrating ADHNs into the community and addressing specific local needs and preferences is crucial for getting the project off the ground. This favors strong local grounding of the parties involved in the governance arrangement. • The implementation and scaling phases require significant investments, necessitating payback periods with a long horizon rather than a quick return on investment. This favors the inclusion of public actors with financial power in governance arrangements and the structuring of these arrangements to accommodate longer payback periods than are commercially typical. • In the exploitation phase, ADHNs benefit from efficient business operations, ensuring activities like billing, customer service, and administration are performed effectively. These tasks are strongly associated with commercial parties. • The Mijnwater case may serve as a source of inspiration on leveraging differing governance arrangements suited for differing phases in ADHN development.
Deliberation 7:	*To what extent can we use supra-municipal governance arrangements for ADHNs in Fryslân, and what would that look like?*
Reason:	A form of supra-municipal governance arrangement for ADHNs, such as regional or provincial, is deemed a logical choice by Frisian policymakers and has proven effective in Gelderland. However, the specific operationalization of such a governance arrangement has not been pursued, leading to differing views and expectations among policymakers. Therefore, this deliberation aims to make this concept more concrete so that local developments can incorporate the future implications of supra-municipal governance arrangements in their current decision-making.

Continued on the next page

Considerations:	• Supra-municipal governance arrangements can lead to significant positive effects of economies of scale, especially concerning available manpower, experience and cost-saving. • If preferential, local control and governance could be integrated into a looser supra-municipal governance arrangement, dividing decision-making power and responsibilities according to what is most beneficial for each role and task in the aquathermal heating chain. • The standardization of governance arrangements for ADHNs through supra-municipal elements in them may lead to less complexity, but to achieve this local diversion form the standard must be kept to a minimum.

7.2. VALIDATION

In this section, we describe the validation of the decision-making framework, formulate the changes to the decision-making framework initiated by the validation and evaluate execution of the validation.

To validate the decision-making framework for designing governance arrangements for ADHNs in Fryslân, we conducted an interactive one-hour workshop with members of the Frisian AE project group 'Missy Wetterwaarmte' at the Provincial government building in Leeuwarden. Eleven policymakers from various Frisian governments participated in the workshop, which took place during the project group's bi-weekly meeting. Following a comprehensive presentation on the research and its findings, the attendees engaged in discussions, reflections, and provided feedback on the decision-making framework. This subsection details the feedback collected during the meeting regarding the framework's validity and outlines how this feedback has been incorporated into the final version of the framework, as presented above. An example of the slides used in the presentation is shown in Figure 7.1.

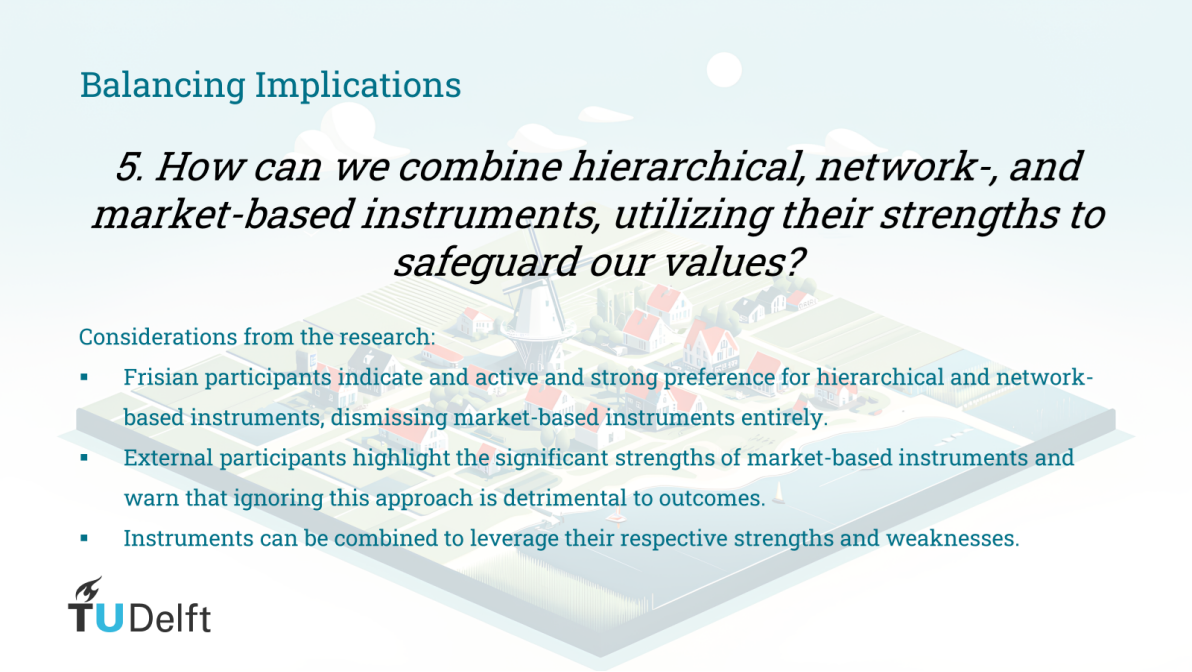

Figure 7.1: Example of a slide presenting one of the deliberations of the decision-making framework in the workshop. It has been translated into English from the originally Dutch slide.

The point led to the most lively discussion was the group's stated goal of connecting 60,000 homes to ADHNs by 2030. Some attendees explained that this goal was established because AE serves as a compelling

conversation starter for realizing DHNs in general, due to their "huggable" nature. However, other attendees seemed surprised by this notion. The disagreement highlighted the importance for policymakers in Fryslân to align their intentions and goals to ensure they are working towards the same objectives. This alignment is crucial in any governance design, as it involves identifying the desired changes.

As a result of this discussion, we revised the decision-making framework to include two deliberation phases on the identification of changes. The first phase focuses on the general intention of policymakers, and the second phase centers on their commitment to specific goals. This structured approach helps policymakers formulate clear and attainable goals and understand the implications for their actions.

However, the workshop did not lead to other significant validation insights that warranted changes to the decision-making framework, as the discussion and reflection on the deliberations did not unfold as we envisioned. The one-hour session, which also included a presentation of the research, proved insufficient for in-depth discussion. Overall, we feel we were insufficiently able to effectively manage the limited time and group dynamics to foster a productive discussion and insightful reflection on the decision-making framework, especially in light of our expectations for the session. This limitation will be further addressed in the limitations section in Chapter 8.

8

Discussion

In this chapter we discuss the results in the context of the existing scientific literature, the academic and societal contributions made by this research, the limitations to the findings and conclusions, and finally the recommendations for future research.

8.1. Results

In this section, we discuss the results of this research, by comparing and contrasting them with existing scientific literature on the same or similar topics. Then, we place the findings of this research into the broader context of the scientific literature on the energy transition and climate change policy.

8.1.1. Comparison with Similar Studies

In this research, we found that participants expressed a conceptual differentiation between centralized and decentralized ADHN-systems with explicit consequences for governance arrangements, in accordance with Scholten and Künneke (2016), who link technical specifications to governance implications, but also in line with Kleiwegt et al. (2023) and Van Popering-Verkerk et al. (2021) on centralized and decentralized ADHNs. While participants to this study echo the assertion by T. Hoppe et al. (2024) that cross-sectoral alignment is crucial in Frisian governance arrangements for ADHNs, they do not address the potential friction between Fryslân's bottom-up approach to ADHN governance and the possibilities for cross-sectoral alignment that is identified in this study.

We found that Frisian culture significantly influences preferences in governance arrangement elements, as well as the suitability of both technical and governance designs. The Frisian cultural affinity with ADHNs expressed in direct quotes in this research closely resembles interview quotes in Van de Witte (2023). Moreover, the Frisian preference for network-based policy instruments and community-based governance arrangements, also aligns closely with the findings of that study. In contrast, however, we further observe a strong preference for hierarchical instruments, particularly in the future establishment of municipally controlled integrated heating companies for the governance of ADHNs as well as a strong rejection of market-based governance arrangements in Fryslân, while these attitudes are not identified by Van de Witte (2023). This is also in stark contrast with T. Hoppe et al. (2024), which states large-scale implementation of AE in Fryslân is "considered not possible without establishing public-private partnerships" (p. 39). This statement does

not align with what Frisian participants in this study express, who consider large-scale implementation of AE without involvement of private parties in governance arrangements to not only be possible but preferable.

Moreover, the observed Frisian preference for municipal integrated heating companies seems more far fetched when compared to the Rotterdam case study in (Hooimeijer et al., 2016). In this study, the case of the Rotterdam heating company is considered, which turned out to be not financially feasible for an integrated company, eventually splitting into a public transportation company and a PPP for the heating company. Interestingly, in this case the heat source was industrial waste heat, which is much cheaper than (centralized) aquathermal heat (NP RES, 2020).

According to a further analysis of the Rotterdam case in Hawkey and Webb (2014), the collaboration between private and public actors eventually turned out to be the key for the project to become reality. Altough the Rotterdam case concerns a more conventional DHN, the findings on the case are in accordance with the found importance of PPPs for ADHNs in this research. Furthermore, PPPs are also found to be crucial in AE by T. Hoppe et al. (2024).

Furthermore, Hooimeijer et al. (2016) divide the governance of DHNs into differing phases, which aligns with the finding in this research that phased governance is may be a prudent approach to designing governance, based on the Mijnwater case. Additionally, Kleiwegt et al. (2023) and Van Popering-Verkerk et al. (2021) indicate similar recommendations for the governance of ADHNs.

A final important distinction between the findings of Van de Witte (2023) and this research is the perspective on whether ADHNs are a means or an end. While our interviews reveal that this remains an open question in crucial need of being addressed, Van de Witte (2023) asserts, based on numerous interviews, that there is a shared vision stating "aquathermy should always be a means and not an end" (p. 33). This discrepancy is further highlighted by conflicting expressions from participants in this study during individual interviews and the plenary validation workshop. This raises questions about the validity of the interview data in this study, whether it was correctly interpreted, or if the participants to the workshop provided answers that presented themselves in a more favorable light rather than the truth.

8.1.2. BROADER GOVERNANCE OF ENERGY TRANSITIONS CONTEXT

The findings of this study on the governance of ADHNs in Fryslân align with key themes in the broader discourse on energy transition governance.

Our research highlights numerous specific characteristics of regional governance in the energy transition, both within the Netherlands and beyond. The Dutch regional energy transition is inherently a cross-sectoral, cross-boundary, and multi-level governance challenge, resulting in a complex, multi-actor governance environment (Cash et al., 2006; Gupta, 2007; T. Hoppe & Miedema, 2020; Warbroek et al., 2023). Our findings affirm and strengthen this characterization. Furthermore, the need for clear, region-specific governance structures and the integration of diverse stakeholders, as observed in Fryslân, aligns with similar needs identified in other regions undergoing energy transitions. This underscores the broader challenges of implementing sustainable energy technologies in diverse regional settings (Hawkey, 2014; Lavrijssen & Vitéz, 2021; Termeer et al., 2011; Vitéz & Lavrijssen, 2020).

In particular, the significance of local cultural factors highlights the necessity for tailored governance approaches that consider the specific cultural and social dynamics of the region (Dobravec et al., 2021; Wagemans et al., 2019). By integrating these localized considerations, governance frameworks can more effectively address the unique challenges and opportunities presented by the energy transition. Therefore, our findings further emphasize the importance of designing governance structures that recognize local institutional contexts while also leveraging the regional scale to achieve more effective and efficient governance outcomes.

The significant and growing importance of community initiatives in the Frisian energy transition mirrors a

broader development in energy transition governance in the Netherlands and beyond. Community initiatives in the energy transition, such as energy or heating cooperatives, are increasingly vital in the governance and realization of sustainable energy projects and infrastructures across Europe (Ancona et al., 2022; Dobravec et al., 2021; Hufen & Koppenjan, 2015; Johansen & Werner, 2022; Proka et al., 2018; Wagemans et al., 2019). This growing importance necessitates that local and regional governments effectively manage and govern these bottom-up entities. In particular, questions remain regarding the legal implications of potentially integrating such actors into formal governance and ownership structures of energy infrastructures. Establishing effective forms of cooperation, collaboration, and alignment of intentions between these community initiatives and local governments remains a significant governance challenge.

Looking ahead, our research suggests that the future of the energy transition will heavily depend on the ability to design and implement flexible, context-sensitive governance frameworks. These frameworks must effectively integrate diverse stakeholders and navigate the complexities of governance across jurisdictional and sectoral boundaries. The case of Fryslân illustrates that successful energy transitions require not only technical solutions but also robust governance structures adaptable to local conditions and capable of fostering collaboration among various actors. Additionally, it highlights the importance of learning from the experiences of peer governments to avoid potential pitfalls and enhance governance design. Through this research, we introduce a valuable new tool for studying the energy transition. By integrating both the institutional and technical implications and trade-offs in energy infrastructures with an in-depth governance arrangement-based analysis, we have established a new operationalization of the analytical lens. This approach allows for a comprehensive examination and design of a broad range of sustainable energy infrastructures. We will further reflect on the academic contribution of our research in the next section.

8.2. REFLECTION ON RESEARCH CONTRIBUTION

In this section, we reflect on the academic and societal contribution this research offers.

8.2.1. REFLECTION ON ACADEMIC CONTRIBUTION

The academic contribution of our research is twofold. First, we provide novel empirical insights into the governance of ADHNs in Fryslân specifically, as well as on the governance of the heat transition in general. Second, our research offers a theoretical innovation and operationalization for the analysis and design of governance for energy infrastructures by integrating two existing frameworks, by adding the depth of governance arrangements based analysis to the comprehensive design of energy infrastructures framework.

NEW EMPIRICAL INSIGHTS

First, this study presents previously unobserved empirical insights into the governance of ADHNs, significantly enriching the existing body of knowledge on this subject. The specific examples discussed in the previous section exemplify the unique contributions of this research. By focusing on ADHNs in Fryslân, we have shed light on a region-specific energy infrastructure governance context that has not been comprehensively examined before, offering fresh perspectives and deepening the understanding of regional governance practices in the context of energy transitions. More broadly, our research makes a substantial contribution to the academic understanding of the general governance dynamics in the region. One of the key findings is the significant influence of Frisian culture on governance decisions. This identified cultural impact underscores the necessity of considering local cultural factors in the design and implementation of governance frameworks. The study reveals how cultural values and norms shape governance processes, decisions, and outcomes, providing a nuanced understanding that can inform both local and broader governance strategies.

Additionally, the research uncovers an existing ambition within the region to align efforts across sectoral

boundaries, despite notable challenges in implementation. This finding is crucial as it points to the potential for integrated governance approaches that can enhance the efficiency and effectiveness of energy transition initiatives. By documenting these aspirations and the associated obstacles, the study offers valuable insights into the practicalities of achieving cross-sectoral collaboration, which is essential for effective governance arrangements. Moreover, the research identifies the evolving role of the Province of Fryslân amid changing financial perspectives. This shift highlights the dynamic nature of regional governance and the need for adaptive governance structures that can respond to evolving financial and policy landscapes. The analysis of the Province's changing role provides a case study in how regional authorities can navigate and influence the governance of energy infrastructures in response to external pressures and opportunities.

Moreover, by adopting an exploratory approach, this research not only takes the first steps towards the design of the most suitable governance arrangements for ADHNs in Fryslân but also sets the stage for more focused and detailed future research. The exploratory nature of our study has provided a broad examination of various factors influencing governance, providing a comprehensive baseline of knowledge. This initial investigation uncovers key themes and dynamics that can be further explored and refined in subsequent studies. We have highlighted specific cultural, sociological, technical and political influences that shape governance decisions. By identifying these factors, we provide a point of departure for more targeted research that can delve deeper into the intricacies of these influences. This foundational work will enable academics to build on our findings, employing more specialized methodologies to investigate the complexities of ADHN governance in Fryslân and beyond. Furthermore, the insights gained from this research contribute to a broader understanding of governance in the context of the energy transition. By highlighting the interplay between technical systems and governance arrangements, our study paves the way for future research to develop more effective and contextually appropriate governance frameworks for energy infrastructures. Later in this chapter, we provide concrete suggestions for future research to build upon this foundational work and continue advancing the field.

THEORETICAL INNOVATION

Second, we contribute to academia by providing a theoretical innovation in the form of a more comprehensive and operationalized tool for the analysis and design of governance for energy infrastructures through the integration of the governance arrangements framework by Termeer et al. (2017) into the comprehensive design of energy infrastructures framework by Scholten and Künneke (2016). Operationalized frameworks for the design of governance are relatively rare in academic literature, particularly in the context of energy infrastructures. This scarcity is particularly problematic given the increasing importance of the energy transition and the emergence of new sustainable energy infrastructures, which necessitate novel governance structures and approaches due to their significant technical differences from conventional infrastructures. Therefore, our integration of these frameworks addresses a critical gap in the academic literature by offering a more in-depth and operationalized approach to the governance of energy infrastructures, thereby enhancing the 'comprehensive' nature of the design approach, as is also explicitly called for in Scholten and Künneke (2016). This theoretical innovation is valuable for academia for two main reasons.

First, our integrated framework provides a tool for the research and design of energy infrastructures with enhanced analytical rigor. The original comprehensive design of energy infrastructures framework consists of a four step approach to designing energy infrastructures on a governance and systems engineering front. The third step of this four step approach is the identification and interpretation of the implications of a 'system change' - the introduction of a new energy infrastructure - to the broader socio-technical system. For an in-depth analysis of the (proposed) energy infrastructure in this step, it is essential to ensure implications are considered for all aspects of governance. This raises the question of how we can ensure we include a compre-

hensive collection of governance aspects in our analysis. Moreover, in addition to implications having to be identified, they also have to be interpreted correctly. Therefore, a structured approach to this identification and interpretation of governance implications is crucial. To structure this process, we have introduced the usage of Termeer et al.'s seven elements to address in governance arrangements framework. By applying this framework, we ensure governance implications are identified for all crucial (seven) elements of governance arrangements and that these implications are interpreted based on specific theoretical argumentation based on the description of the seven elements by Termeer et al. (2017). Therefore, our theoretical innovation of integrating the two frameworks has created a more comprehensive and in-depth tool for the academic analysis and design of governance for energy infrastructures.

Second, while we have demonstrated the framework's utility within the specific context of Fryslân, its principles and methods can be adapted to other regions and types of energy infrastructures. This adaptability enhances the framework's value as a versatile tool for governance analysis and design. The theoretical innovation presented in this thesis establishes a foundation for future academic inquiries, highlighting key areas for further exploration such as adapting the integrated framework to different contexts and developing additional tools to enhance its application. By paving the way for continued research, this thesis significantly contributes to the ongoing evolution of the field of energy governance. We provide concrete suggestions for future research later in this chapter.

8.2.2. REFLECTION ON SOCIETAL CONTRIBUTION

Through this research, we have contributed significantly to societal goals in various ways. In this section, we reflect on the societal contribution of our research.

First and foremost, our research directly contributes to climate change mitigation efforts by providing a decision-making framework for governments and policymakers that facilitates the design of governance for ADHNs, by which we are removing barriers in the process of developing these infrastructures. By streamlining the transition in Fryslân from gas-fueled heating infrastructure to sustainable collective heating infrastructures such as ADHN, we are contributing to the mitigation of greenhouse gas emissions (Rijksoverheid, 2019a).

Second, by facilitating the development of ADHNs through streamlining governance design processes, we are indirectly promoting the development of the regional economy. Ensuring ADHN governance is designed to be suitable for the Frisian context specifically, means governments in the region can fulfill their ambition to connect ADHN implementation directly to regional economic development, keeping wealth creation local (Provincie Fryslân, 2021).

Third, by promoting the adoption of ADHN infrastructures in Fryslân through the facilitation of developing suitable governance arrangements, thereby in turn replacing gas-fueled heating infrastructure with electricity-based alternatives, we also contribute to the overall energy independence of the Netherlands (Sampedro et al., 2024).

Lastly, by providing a substantiated and comprehensive decision-making framework for designing ADHNs governance specifically suitable to the Frisian region and its governments' core values, we are ensuring future governance of ADHNs effective and appropriate to the context. By ensuring that critical considerations are included in the design and implementation of governance arrangements for ADHNs, we have provided policymakers with the tools needed to design governance structures that are both effective and suitable for their intended goals, leading to a more resilient and sustainable energy infrastructure. This in turn will lead to better societal outcomes (Termeer et al., 2011; Van der Schoor & Van der Windt, 2023).

In summary, the societal relevance of our research has been affirmed through its contributions to environmental sustainability, economic development, energy security, and governance efficiency. These outcomes

reflect the alignment of our work with overarching societal goals and highlight the impactful role that well-designed governance frameworks can play in achieving sustainable development.

8.3. LIMITATIONS

In this section, we discuss the research limitations to be considered in the interpretation of the findings and conclusion.

8.3.1. THEORETICAL LIMITATIONS

During the research process, it became apparent that the development stage of ADHNs and their governance in Fryslân was less advanced than initially anticipated. Consequently, the application of two frameworks intended for the concrete design of governance to infrastructures still in the conceptualization phase limits the depth of our findings. Since (pilot) implementations of the infrastructures in the region could not be observed, and the performance of their governance and subsequent outcomes could not be evaluated, our findings remain conceptual. These insights are primarily derived from from Frisian participants' expressed expectations regarding the implications of various governance choices rather than their observations, and from expert opinions on similar infrastructures in other regions, whose applicability to the Frisian context can be conceptually argued but not definitively verified.

Moreover, although we argue that our integration of the comprehensive design of infrastructures framework by Scholten and Künneke (2016) and the governance arrangements framework by Termeer et al. (2017) is a theoretical innovation, this also limits the interpretative scope of our findings. Having never been applied in this manner before, there is no basis for comparison for the application and outcomes of our theoretical approach, limiting possibilities for validation of results. This affects the certainty with which we can state our conclusions are reliable.

The exploratory nature and broad scope of this research have constrained the depth of the findings and, consequently, the specificity of the research conclusions. By examining ADHN governance across the entire Frisian region, it became evident that significant variations exist depending on the organization involved and the specific project under study. This approach resulted in the collection of data from participants engaged in diverse implementations of ADHNs at various developmental stages. As a result, the observations made are more general than they would have been if the research had focused on designing a governance arrangement for a specific ADHN within a particular area in Fryslân.

8.3.2. METHODOLOGICAL LIMITATIONS

Although we interviewed numerous experts on both the Frisian case and external cases of ADHNs or similar infrastructures, in hindsight, more targeted and in-depth insights could have been achieved with a more focused selection of participants. Specifically, including more participants from community initiatives and energy cooperatives, which were found to be crucial in the Frisian approach, would have been beneficial. Only one expert from these groups was interviewed. Moreover, including participants from organizations potentially involved in future governance arrangements, such as Firan, Energie Beheer Nederland (EBN), and the Frisian Clean Energy Fund (FSFE), would have shed light on their willingness and feasibility as stakeholders. Interviewing policymakers from municipalities not currently at the forefront of ADHN governance could have highlighted considerations for wider implementation in the region. The exploratory nature of this research revealed the relevance of these organizations too late to include them, limiting the comprehensiveness of the insights.

Another methodological limitation pertains to the roles of interview participants in relation to ADHNs.

Both within Missy Wetterwaarmte and our participant pool, there are numerous individuals engaged more in management than in policy development. This distinction is relevant to the interview outcomes, as manager-type participants, particularly project or process managers, may be less inclined to critically reflect on the current policy direction. Their roles typically involve executing policy rather than formulating it. For example, a participant from a municipality with the job title 'Process Manager Energy Company' is likely less critical of the concept of a municipal energy company compared to a policy advisor, as their focus is on managing the implementation rather than questioning its foundational premise. Consequently, the inclusion of various manager-type participants in this study may influence the data collected through interviews.

Furthermore, the execution of the validation workshop was not as it was designed, leading to significantly less validation efforts than intended. The one-hour session proved insufficient for in-depth discussion. The workshop was dominated by a disagreement between two attendees over centralized versus decentralized ADHN configurations, which stifled broader contributions and shifted focus away from governance issues. Additionally, participants appeared entrenched in their existing views on governance directions, showing little openness to external concerns or alternative designs. Especially considering the inherent limitations of exploratory, qualitative research, the lack of proper validation limits the applicability of findings in this research.

The validation workshop also revealed limits to the interview data due to the differences we observed in participant expression between individual interviews and group settings. For example, in interviews, participants were openly critical of their own and others' actions in ADHN-governance. However, in the workshop, discussions were more reserved and there was broad consensus on the current strategy and direction of ADHN-governance arrangement design, even when confronted with concerns from the Frisian interviews. This contrast, especially evident with interviewees also present at the workshop, limits the decision-making framework's applicability in collaborative government projects, as key critiques seemed to be omitted in the group discussion.

8.4. FUTURE RESEARCH

Due to the exploratory nature of this research, more specific research efforts can further shed light on the topics covered in this research. Therefore, in this section, we suggest directions for future research, both seeking to further explore the case of ADHN governance in Fryslân as well as the heat transition in general.

8.4.1. THE GOVERNANCE OF ADHNS

From this research, we can recommend a number of avenues for future research on the governance of ADHNs.

- **Further develop and design concrete governance arrangements for specific ADHNs in Fryslân.** Building on this exploration of governance arrangements for ADHNs in Fryslân, future research could use the decision-making framework to develop more concrete governance arrangement designs. Moreover, once pilot projects of ADHNs have been or are being implemented in the region, future research should seek to use empirical observations of concrete technical choices and specific governance outcomes to come to a concrete governance design for a specific ADHN in Fryslân. By specifically focusing on one ore more (pilot) ADHN projects in the region, governance arrangements can be designed more concretely. Interesting potential cases, which are expected to start physical development soon, are the Warm Heeg, Eigen Warmte Balk and Leeuwarden aquathermal projects.

- **Conduct comprehensive comparative case studies.** Our exploratory research has given useful insights into the governance of ADHNs in Fryslân and has identified cases of energy infrastructure governance

that could provide relevant comparative insights to the Frisian case. Therefore, we recommend future research to take on a comparative case study approach to further examine the governance of ADHNs in Fryslân and in general, via two possible routes. First, a comparative case study of the governance implemented (pilot) central and decentral ADHNs in Fryslân could provide deeper insights of the governance implications of the technical differences in ADHNs as identified in our research. Second, a side-by-side comparative case study of the Gelderland, Limburg or Danish cases would yield more valid and detailed insights into governance structures and their implications for Fryslân than our initial exploratory research has provided.

- **Approach ADHN governance from other governance perspectives.** As we have observed in this research, the governance of ADHNs in Fryslân, as well as other regions, is influenced by local communities, and municipal, regional, provincial, and national government entities, all within the framework of European regulations. However, this research has not explicitly analyzed the dynamics of governance across these multiple levels. Future research could address this gap by utilizing the multi-level governance framework presented by Hooghe and Marks (2001). Additionally, the observed dispersed nature of the development of rural ADHNs such as in Fryslân suggests that a polycentric governance perspective, as described by Ostrom (2010), could provide valuable insights. Lastly, we recommend exploring the governance of ADHNs in Fryslân specifically from a collaborative governance theoretical perspective, given the observed collaborative efforts between governments in the region, particularly through the Missy Wetterwaarmte project group. A starting point for this theoretical approach could be the work of Ansell and Gash (2008).

- **Evaluate governance outcomes in Súdwest Fryslân.** Future research should evaluate the governance outcomes in Súdwest Fryslân, where an integrated municipal heating company is being established, despite the emphasis on the crucial importance of PPPs by T. Hoppe et al. (2024). This investigation should assess the effectiveness, efficiency, stakeholder engagement, financial viability, and environmental impact of the municipal approach compared to more concentional PPP-based governance models. By examining these aspects, researchers can provide valuable insights into the relative strengths and weaknesses of different governance structures, informing future policy decisions and contributing to more effective and sustainable heating infrastructures in Fryslân and beyond.

8.4.2. GOVERNANCE OF ENERGY TRANSITIONS

Based on the research we conducted, we have identified new directions for research on the governance of energy transitions in general.

- **Further scrutinize, validate, operationalize and apply our integrated framework.** As discussed earlier in this chapter, our integrated framework provides a more operational and in-depth tool for the analysis and design of governance in the energy transition. However, as of now it remains insufficiently validated and scrutinized. Moreover, the applicability of our integrated framework to other cases than ADHNs in Fryslân has also not been tested. Therefore, future research should seek to validate and scrutinize our framework by applying it to various cases of (energy) infrastructures, ADHNs and others, both in Fryslân and elsewhere. In doing so, researchers can further improve our integrated framework, leading to the improvement of academic tools for the analysis and design of governance of (energy) infrastructures. Furthermore, our integrated framework does not address all required operationalizations as stated by Scholten and Künneke (2016). Future research could seek to enhance the framework by further operationalizing the desired degree of alignment between institutional and technical as-

pects, which may not always be to be fully aligned, as well as the representation of the dynamic nature of energy infrastructures, as opposed to the static nature of this framework (Scholten & Künneke, 2016).

- **Examine the large-scale implications of the bottom-up approach to the energy transition.** This research has identified significant tension between fostering community initiatives, such as energy communities or heating cooperatives, and the larger scale goals such as achieving economies of scale, regional standardization and intersectoral alignment. Community initiatives are becoming increasingly important for the Dutch and European energy and heating transitions, as for instance highlighted by the WaterWarmth project. Our findings suggest that these bottom-up entities present trade-offs for projects and infrastructures, including the standardization of technology and governance processes, regional technical integration, and alignment of policy sector choices. Future research should aim to uncover the extent and significance of these effects, explore strategies for mitigating them, and assess the implications for the preferability of fostering bottom-up community initiatives within the broader context of the European energy transition. Futhermore, future (formal) roles of community initiatives and cooperatives in sustainable energy infrastructure governance arrangements and ownership structures need to be further explored, specified, designed and their implications analyzed through extensive academic research.

- **Investigate the impact of uncertainty in legal frameworks on the speed of the energy transition.** The Dutch Collective Heating Law, currently under development for parliamentary discussion, has already significantly influenced governance decisions by policymakers, who are preparing for its eventual implementation. The uncertainty surrounding this legislation may have led to inaction or the exclusion of certain effective commercial stakeholders from governance arrangements. Future research should explore the impact of uncertainty surrounding laws and regulations concerning specific energy transition technologies and infrastructures. As an example of a research project, one could explore the broad impact of the potential Collective Heating Law on current governance decisions within theDutch heat transition. This investigation should adopt a combined juridical and governance approach to comprehensively understand how the uncertainty and potential outcomes of this legislation affect strategic planning and stakeholder involvement in the Dutch heat transition.

9

CONCLUSION

To achieve a sustainable heating supply in the built environment, governments in Fryslân aim to connect 60,000 homes to Aquathermal District Heating Networks (ADHNs) by 2030. However, the realization of ADHNs is hindered by a lack of governance arrangement designs specifically suited to the Frisian context. To address this, we conducted exploratory research based on qualitative methods which included semi-structured interviews with experts from inside and outside the Frisian system, thematic data analysis of interview transcripts, and validation through an interactive workshop with representatives of the members of the Frisian Aquathermal Energy (AE) project group. Consequently, we were able to explore and analyse the Frisian context, the governance implications of ADHNs, and possible governance arrangement design directions. In this chapter, we will formulate and answer to the main research question and give policy recommendations.

9.1. MAIN RESEARCH QUESTION

Based on the empirical results and analysis in this research we can answer the main research question of this research: *What deliberations and considerations should be included in a decision-making framework for designing governance arrangements of aquathermal district heating networks in Fryslân?*

We have formulated seven deliberations as part of a decision-making framework to facilitate and structure the design process for governance arrangements for ADHNs in Fryslân. The decision-making framework is intended for use by Frisian governments and specifically their policymakers working on the ADHN dossier. This framework ensures that necessary decisions are made by policymakers and that important considerations are addressed. The decision-making framework consists of three steps: (1) defining system changes; (2) balancing implications; and (3) exploring design directions. These steps are derived from the final three stages of the comprehensive design framework.

In the first step, policymakers are asked to comprehensively define and align the system changes they are aiming to achieve. This is important due to the observed differences in definitions of ADHNs as a technology, their future place in the Frisian heating sector, governments' commitment to the stated objective, and whether ADHNs are a means or an end. Moreover, the pace of development and commitment of governmental resources in the region is currently unaligned with the stated objective. Therefore, before designing any specific governance arrangements for the exploitation of ADHNs, policymakers should re-examine the policy objective, reflect on whether ADHNs are a means or an end, and align resource commitment with objective

commitment, by deliberating; 1. *To what extent should ADHNs be a goal of their own, and why?*, and; 2. *How committed are we to the ADHN-goal, and how should that be reflected in committed resources?*

The second step facilitates informed decision-making in the design of governance arrangements by guiding policymakers to weigh crucial and conflicting governance implications of ADHNs in Fryslân. Given the external concerns regarding the feasibility and unconventional nature of Frisian governance preferences, it is essential to challenge and critically reflect upon these preferences, to ensure the design of suitable and effective governance arrangements. Thus, policymakers should reflect, discuss and decide on three deliberations; 3. *How can we balance integration and standardization with the bottom-up approach?*; 4. *How can we balance the risks of acting too early versus too late?*, and; 5. *How can we combine hierarchical, network-, and market-based instruments, utilizing their strengths to safeguard our values?*.

The third step suggests two directions for ADHN governance designs for further exploration by policymakers in Fryslân. First, it proposes dividing governance arrangement designs into separate phases for ADHNs in the region, allowing them to be tailored to the specific circumstances and needs of each phase. A relevant example is the Mijnwater project in Limburg, initiated by a municipality, scaled by the provincial investment fund, and operated through a combined ownership structure between the regional Distribution System Operator (DSO) and the provincial investment fund. Additionally, the concept of a supra-municipal governance arrangement for ADHNs in Fryslân is already part of the policymakers' considerations but has not yet been developed into a concrete proposal. To provide clarity for local ADHN projects regarding future governance, Frisian policymakers should concretize their plans for supra-municipal governance arrangements in the region. These two governance concepts pose interesting design directions, that should be further explored in future, more concrete governance arrangement design phases. Therefore, we include the following two deliberations: 6. *To what extent can we use different governance arrangements and actors in differing phases of ADHNs?*, and; 7. *To what extent can we use supra-municipal governance in Fryslân, and what would that look like?*.

Overall, the decision-making framework outlined in this research provides a structured approach for Frisian policymakers to the design of governance arrangements. By systematically addressing the seven deliberations—ranging from defining system changes and balancing governance implications to exploring phased and supra-municipal governance designs—this framework ensures that all critical aspects are considered. Thus, we facilitate the design of concrete, region-specific governance arrangements for ADHNs in Fryslân.

9.2. POLICY RECOMMENDATIONS

In this section, we present recommendations for the WaterWarmth research project to enhance their ongoing research on AE as well as concrete policy recommendations for governments in Fryslân. First, we formulate the following recommendations for the WaterWarmth research project:

- **Distinguish between individual and collective AE.** Researching AE involves two different types of sustainable heating technologies, even though the core physics are the same. The integration of DHNs with AE technology, creating ADHNs, adds significant complexity compared to individual water source heat pump systems for single buildings. This distinction also has explicit governance implications. Therefore, it is imperative to clearly differentiate between individual and collective AE systems in research, both in general and specifically for governance purposes.

- **Investigate the integration of energy communities in ownership structures.** Examine the existing legal, operational, and regulatory concerns associated with assigning formal roles to energy communities in ADHN governance arrangements, especially concerning ownership in the aquathermal heating

chain during exploitation. Assess the validity of these concerns and develop solutions to facilitate the increased involvement of these entities in ADHN governance.

- **Investigate the influence of potential regulatory changes.** National competition laws and the resulting feasible market designs for District Heating Networks (DHNs) are critically important to the future governance of ADHNs. The potential future implementation of the Dutch Collective Heating Law and the surrounding uncertainties are currently a significant factor in all design efforts for ADHN governance arrangements. Therefore, it is essential to assess how these regulatory changes might impact the governance of ADHNs, for instance by developing governance scenarios depending on the eventual specifics of the Dutch collective heating law.
- **Expand the exploration of potential stakeholders in ADHN governance.** We have identified significant future stakeholders not included in this research, particularly existing (semi-)public entities well-suited to governance roles. Future research efforts by WaterWarmth should include a broader range of potential stakeholders, such as Distribution System Operators (DSOs), utility companies, regional investment funds, and companies currently managing the existing (gas) heating systems.

Second, we formulate the following policy recommendations for governments in Fryslân:

- **Design concrete governance arrangements for ADHNs.** To effectively transition from the current pilot phase to the development, scaling, and exploitation of ADHNs in the region, it is crucial to create governance structures tailored to the Frisian context. Governments in Fryslân should utilize the decision-making framework outlined in this research to establish clear and concrete governance arrangements, facilitating the next steps toward large-scale ADHN implementation.
- **Establish concrete location designations for ADHNs as soon as possible.** The financial viability of ADHNs is at risk due to residents adopting individual sustainable heating solutions. To mitigate this risk, it is crucial to implement the municipal transition visions for heating on a neighborhood scale, providing concrete designations of heating technologies for specific areas. Clear and early communication of these plans will help residents understand their future heating options, reducing the likelihood of premature adoption of individual solutions.
- **Critically assess municipal roles in collective heating systems.** Frisian governments may be overly optimistic about municipal capacities to establish, finance, and manage (integrated) heating companies. This poses significant risks for the effective operation of collective heating systems, including aquathermal ones. Before pursuing this approach, it is crucial to learn from experiences that led to its dismissal in other parts of the Netherlands, such as the cases of the municipality of Nijmegen and the Rotterdam heating company.
- **Foster Public-Private Partnerships.** Engaging private parties is essential for the effective and efficient implementation and governance of ADHNs, as they provide critical financial resources, expertise and manpower. This can be established through collaboration between governments and private parties. Excluding private entities would result in missed opportunities and unnecessary duplication of efforts by the government as well as a venture into activities unsuited to (local) governments. Public interests can be sufficiently safeguarded through clear rules, and regulations, as well as divisions of responsibilities and divisions of decision-making power.
- **Integrate heating policy with housing policy.** The ambition to build thousands of new homes in Fryslân should be aligned with heating policy. Allowing new housing developments to adopt individual

sustainable heating solutions represents a missed opportunity to optimize the region's limited renewable electricity capacity and address net congestion. Housing projects should prioritize implementing collective heating systems, such as ADHNs. Individual sustainable heating solutions should only be considered when a collective solution is not feasible

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A

Semi-structured Expert Interviews

This appendix contains the interview guides to conduct interviews and the informed consent statement participants agreed to in order to participate.

Interview Guides

This appendix contains the interview guide designed to serve as the foundational document for conducting interviews for this study. It outlines the entire interview process, providing both the script and questions for the interviewer to ensure consistency across all interviews. It is important to note, however, that given the semi-structured format of these interviews and the varied backgrounds of the interviewees, the interviewer has the discretion to depart from the guide when necessary to accommodate the flow of conversation or to explore pertinent topics in greater depth.

Universal introduction to the interview (ca. 2 minutes)

Thank you for agreeing to this interview on the governance of aquathermal district heating networks, which is part of my thesis research for the Complex Systems Engineering & Management master's program at TU Delft. The goal of this interview is to gain insight into the what the most suitable governance arrangements for future aquathermal district heating networks in Friesland might look like. 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. Furthermore, I would like to clarify what I mean when I use the term *governance arrangements* and what the end result of this research project will be. In this research, by governance arrangements we mean the specific rules, processes, and instruments that structure the interactions between public and/or private entities to realize collective goals for a specific domain or issue. The end goal of this research is to clearly define deliberations for policy makers involved in the development of aquathermal district heating networks in Friesland concerning the most suitable governance arrangements. 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?

Friesland Case Questions

Part I: Introductory questions (ca. 5 minutes)

1. Could you briefly introduce yourself, the organization you are affiliated with, and describe how are you involved in the realization of aquathermal district heating networks in Friesland?
2. Could you give a brief examination of the current and future state of aquathermal district heating networks in Friesland? What does aquathermal energy in Friesland look like today and how will that change in the future?

Part II: Questions concerning the social-, technical- and governmental context of aquathermal energy in Friesland (ca. 20 minutes)

3. When we discuss aquathermal energy and aquathermal district heating networks, what does that mean to you, in a technical sense?
4. What factors currently inhibit the realization of aquathermal networks?
5. How would you describe the culture of governance and government in Friesland and do you feel that this is beneficial to the management of infrastructures?
6. What public and/or private parties should be involved in aquathermal district heating networks, particularly in the exploitation phase?

Part III: Questions concerning the seven elements to address in governance arrangements according to Termeer et al. (2017) (ca. 30 minutes)

7. Considering the public and/or private parties to be involved in the governance of aquathermal district heating networks (mentioned in the previous question), what prerequisites might push parties from different sectors (housing, energy, water) to cooperate effectively? *(Alignment across Sectoral Boundaries)*
8. Are any perceptions of aquathermal district heating networks held by stakeholders that inhibit the implementation thereof? *(Framing)*
9. At which scale-level should aquathermal district heating networks be governed, and what roles should other levels of government play? *(Levels of Action)*
10. To what extend do you feel that aquathermal district heating networks as a technology are mature enough to be rolled out on a large scale? *(Timing of Policies)*
11. Considering hierarchy-, market- and network-based approaches towards influencing the (inter)actions of stakeholders of aquathermal district heating networks, which approach do you feel is most appropriate and why? *(Selection of Policy Instruments)*
12. To what extent do policymakers in Friesland have knowledge of the science concerning the technical and governance aspects of aquathermal district heating networks? *(The Organization of the Science-Policy Interface)*
13. Considering the differing types of stakeholders surrounding aquathermal district heating networks (Province, municipalities, communities, housing companies, energy companies, etc.), in your opinion, who should take the initiative to realize aquathermal district heating networks in Friesland and why? *(The Appropriate Forms of Leadership)*

Part IV: Closing the interview (ca. 3 minutes)

14. Are there any documents or experts that I should strongly consider consulting for this research project?
15. Are there any comments you would like to make on the governance of aquathermal district heating that we have not yet discussed?

External Case Questions

Part I: Introductory questions (ca. 5 minutes)

1. Could you please introduce yourself and the organization you are affiliated with, as well as elaborate on the source of your experience with- and knowledge of the governance of aquathermal energy and/or district heating networks?
2. Can you give a brief description of the (aquathermal) district heating network you are involved with, both in technical and governance terms? *(Only if applicable to interviewee)*

Part II: Insights from other cases (ca. 20 minutes)

3. What public and/or private parties should be involved in aquathermal district heating networks, particularly in the exploitation phase? ?
4. In your opinion, what outcomes should a governance arrangement for an (aquathermal) district heating network aim at achieving and why?
5. With the knowledge you have now, what would you change to the governance structures that govern your system?
6. Can you name some *best practices* that have emerged over time in the governance of your system? Why are these helpful?

Part III: Questions concerning the seven elements to address in governance arrangements according to Termeer et al. (2017) (ca. 30 minutes)

7. Considering the public and/or private parties to be involved in the governance of aquathermal district heating networks, what prerequisites might push parties from different sectors (housing, energy, water) to cooperate effectively? *(Alignment across Sectoral Boundaries)*
8. Are any perceptions of aquathermal district heating networks held by stakeholders that inhibit the implementation thereof? *(Framing)*
9. At which scale-level should aquathermal district heating networks be governed, and what roles should other levels of government play? *(Levels of Action)*
10. To what extend do you feel that aquathermal district heating networks as a technology are mature enough to be rolled out on a large scale? *(Timing of Policies)*
11. Considering hierarchy-, market- and network-based approaches towards influencing the (inter)actions of stakeholders of aquathermal district heating networks, which approach do you feel is most appropriate and why? *(Selection of Policy Instruments)*
12. To what extent do policymakers have knowledge of the science concerning the technical and governance aspects of aquathermal district heating networks? *(The Organization of the Science-Policy Interface)*

13. Considering the differing types of stakeholders surrounding aquathermal district heating networks (governments, companies, communities, etc.), in your opinion, who should take the initiative to realize aquathermal district heating networks and why? *(The Appropriate Forms of Leadership)*

Part IV: Closing the interview (ca. 3 minutes)

14. Are there any documents or experts that I should strongly consider consulting for this research project?

15. Are there any comments you would like to make on the governance of aquathermal district heating that we have not yet discussed?

Informed Consent Statement

You are being invited to participate in a research study titled *The Governance of Aquathermal District Heating*. This study is being performed by Floris Groot, a MSc Complex Systems Engineering and Management student from the TU Delft (TUD) and supervised by Dr. Ellen Minkman, assistant professor at TUD.

The purpose of this research study is to determine the most suitable governance arrangements for aquathermal district heating networks. The interview is scheduled to take one hour, unless other arrangements have been made beforehand. The data will be used for a Master Thesis. You will be asked questions about your experiences in your specific field and/or organization that concern governance, aquathermal energy, district heating and/or infrastructures.

Your answers in this study will be processed as confidentially as possible. To anonymize answers, data included in the final report will refer to you not by name but job title and organization (e.g. researcher, TU Delft), unless otherwise agreed to. With your agreement, the interview will be recorded in order to write a transcript for further analysis. You will receive a copy of the transcript.

The personal data collected during this project (transcript of the interview and proof of consent) will be preserved at TUD under the responsibility of Dr. Ellen Minkman. The personal data will be reused within TUD in the context of the WaterWarmth Project. Additionally, the personal data may be shared with partner institutions - in the context of this project.

For the entire duration of the preservation (until the end of the WaterWarmth project in 2026), the personal data collected during this project may be reused for scientific publication, scientific communication or education purposes, on the topic of the governance of aquathermal district heating networks. You will be anonymous in all outputs. Should we want to use the data for any other purposes, we will reach out to you and obtain your explicit permission.

Your participation in this study is entirely voluntary and **you can withdraw at any time.** You are free to omit any questions. If you withdraw, all recorded material from the interview will be deleted.

For any questions, feel free to contact:

[Contact Details of researcher and supervisor not included in thesis]

B

THEMATIC CODES

This appendix contains the thematic codes that resulted from the coding process as described in Chapter 3.

Table B.1: Main Code, Subcode, and Description

Main Codes	**Subcodes**	**Descriptions**
Deductive codes		
Alignment across sectoral boundaries	Alignment is well	Cross-sectoral alignment is at least satisfactory
	Goal-oriented approach	A goal-oriented approach is used to help cross-sectoral alignment
	More alignment necessary	Cross-sectoral alignment should improve
	Mun. more aligned than province	Municipalities have more inherent cross-sectoral alignment due to scale
	Netcongestion / Renewables	Importance of alignment of heating with electricity issues
	New Housing	Importance of aligning heating with housing issues
Framing	AE Expensive	AE is framed as relatively expensive
	Frisian Solution	AE is framed as a particularly 'Frisian' technique
	Linking AE and Electricity	Framing AE as an alternative to building (disliked) wind turbines
	Negative on AE	Misc. negative frames of AE
	Negative on DHNs	Frames specifically negative on DHNs
	No negative frames AE	There are no negative frames surrounding AE
Levels of action	Community Initiatives	Describing the role and importance of community initiatives in ADHNs
	Municipality	Describing the role and importance of municipalities in ADHNs
	National Government	Describing the role and importance of the national government in ADHNs
	Province	Describing the role and importance of the province in ADHNs

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Main Codes	Subcodes	Descriptions
	Water board	Describing the role and importance of water boards in ADHNs
Selection of policy instruments	Hierarchical	Describing or discussing the use of hierarchical instruments for ADHN-policy
	Market	Describing or discussing the use of market-based instruments for ADHN-policy
	Network	Describing or discussing the use of network-based instruments for ADHN-policy
Timing of policies	Individual solutions	(A)DHNs should be implemented as soon as possible, because residents are investing in individual solutions
	Maturity technology	Discussing the level of maturity of (A)DHNs
	Trias Energetica Order	Discussing whether to adhere to the trias energetica order of timing policies
	Pilot projects	Larger implementation is not possible before small pilot projects have been completed
The appropriate forms of leadership	Describing or discussing leadership in ADHN governance in Friesland	
The organization of the science-policy interface	Describing or discussing knowledge levels in ADHNs policymakers	
Technical System Aspects	Technical characteristics of the Frisian heating system that (may) influence the configuration of ADHNs.	
Institutional System Aspects	Institutional characteristics of the Frisian heating system that (may) influence the configuration of ADHNs.	
Inductive Codes		
AE Ambitions	Describing or discussing the origin and feasibility of Frisian AE ambitions.	
AE definitions	Descriptions of AE-systems.	
Barriers	Barriers towards successful development and governance of ADHNs systems	
Frisian Culture (of governance)	Describing or discussing the particular Frisian culture, and how this influences governance in the region.	
Gelderland case	Descriptions of the specific Gelderland (GWIB) case.	
Governance Goals	Descriptions of the goals of any governance arrangement for ADHNs.	
Huggable ("knuffelbaar")	Descriptions of AE specifically as "huggable".	
Payback Period	Describing or discussing payback times for ADHNs, and what influences choices therein.	
Province(s) used to be rich	Describing the financial wealth of provinces in the past, due to the sale of NUON, and relatively less wealth now, impacting provincial roles in governance.	
Public Heating Company	Describing or discussing the positive and negative sides of establishing public heating companies in differing configurations.	
Scarcity	Describing the governmental role of dividing in scarcity.	
Solution Spaces	Describing various alternative solution spaces, possibly of interest for the Frisian context.	
Specific External Insights	Descriptions of specific insights applicable to the Frisian case based on external experience, best practices or insights.	
Standardizing	Describing or discussing the importance and feasibility of standardizing technology and governance practices in ADHNs.	