WP 6 Governance of collective energy systems

#1 Framework and typology to analyse governance of current AE and other relevant heating systems

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WaterWarmth

WP 6 Governance of collective energy systems

#1 Framework and typology to analyse governance of current AE and other relevant heating systems

A GREEN TRANSITION

Index

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Report Summary

The aim of this WaterWarmth project Work Package 6.1 report is to present a number of relevant frameworks available to analyse and/or assess the governance of current heating systems and future energy system innovation, in particular with a focus on aquathermal energy (AE) systems. At the basis of the report was a broad survey of the academic and other literature by project researchers on ways to conceptualise the greater use of AE energy systems in the European Union. To keep the report succinct, and based on discussions by WaterWarmth project researchers, we have decided to present a combination of theoretical approaches to frame and understand AE system transitions instead of the broad collection of frameworks and theories that exist today. These are the Multi-Level Perspective, Strategic Niche Management, Contextual Interaction Theory, the Governance of Change and Community Energy Systems. The report contributes to the project by providing a strategic way to understand renewable energy transition processes, and more specifically, pathways for how AE systems can play a more significant role in a renewable energy system transition in the North Sea Region and beyond. The result is a heuristic that allows practitioners to discover how AE system developments in particular places can be viewed in a broader energy system transition context, the measures that may be needed to guide the transition process, and to gain a deeper understanding about the motivations, cognitions and resources of the actors involved in the energy transition process.

To demonstrate the proposed frameworks, we exemplify using two case studies: AE system development at the household in Sweden, and AE transitions in the Fryslân region, in the Netherlands. For the Swedish case we use the Multi-level Perspective (MLP) framework to provide the background of the niche, landscape level and the socio-technical regime which illustrate the influence of policies and regulations, as well as technologies and markets. For the Netherlands case, we place a stronger emphasis on Contextual Interaction Theory (CIT) framework to analyse how the different actors and their characteristics such as motivations, cognitions and resources influence the interaction process in the planning and implementation of AE systems projects. Using the CIT, we are also able to assess how the specific, structural and wider contexts influence the implementation process as well as how the actors interact with each other. Each case provides a unique structuring, both enablers and hindrances, of the institutional and governance dynamics for AE system innovations in their respective countries. Extending from the exemplary studies, we lastly discuss each of the cases as well as broader insights gained when using the approach, and what it can mean for broader AE system transitions in the European Union.

This report is intended for multiple audiences including but not limited to practitioners aiming to develop AE systems, academics interested in assessing governance processes around AE system development, policy-makers interested in policies and decision-making to promote AE system development.

Chapter 1. Introduction

1.1. Background

Over the years, there has been a consistent rise in the development and use of renewable energy technologies in Europe and the rest of the world (Cabre and Vega-Araujo, 2022). According to the International Renewable Energy Agency (IRENA), renewable energy dominates the global market for new electricity generation capacity and, since 2015, more renewable energy power capacity has been added annually than fossil fuels and nuclear combined (IRENA, 2021). The move towards the use of renewable energy is highly motivated by the need to decarbonise energy systems and lower the reliance on fossil fuels. Such an energy transition will in turn benefit the climate by lowering green-house gas emissions and improving livelihoods for many (IPCC, 2014). As renewable energy sources have positive environmental and health impacts such as reduction in pollution and improved energy access, it is likely that countries will continue to seek energy security solutions in renewable energy sources (IRENA, 2021).

According to the World Economic Forum (WEF), “an effective energy transition can be defined as a timely transition towards a more inclusive, sustainable, affordable and secure energy system that provides solutions to global energy-related challenges, while creating value for business and society, without compromising the balance of the energy triangle” (WEF, 2021: 11). The energy triangle in this case refers to environmental sustainability, economic development and energy security and access. It is in this quest that we see the energy transition discourse take centre stage at the global and local arenas where there is a realisation that renewable energy is key in proving such solutions.

Global conflicts that have been experienced over the years, including the Russian invasion in the Ukraine, have intensified the need to find energy solutions that are less polluting, ensure energy security for all and provide economic stability (Liao, 2023). With the recent less reliable natural gas and oil supplies from Russia, many EU and northern countries have placed greater reliance on renewable energy system development. Furthermore, as a consequence of the conflict, Liao (2023) argues that this has encouraged higher investments in renewable energy in Europe, and “has prompted companies to rethink their business models”, and diversify and invest in energy innovations. The acceptance and large scale implementation of renewable energy also indicates changes in policy and government buy-in. For an energy transition towards a decarbonised economy to take place, there has to be an enabling environment which includes political commitment and flexible policy and regulations structures (Cherp et al., 2018).

There are several renewable energy technologies that are already highly accepted and used in many countries. Among the most popular are wind and solar technologies that have been implemented both at large- and small-scale as well as in hybrid formats, depending on the needs and the area served. The use of heat pumps have also intensified as renewable energy technology that meets the energy needs through use of mechanical systems that transfer heat from cool spaces to warm spaces by moving thermal energy via a refrigeration cycle (IEA, 2022). According to the IEA (2022), “around 10% of space heating needs globally were met by heat pumps in 2021”. Heat pumps are also key in the deployment of aquathermal energy (AE) whereby the pumps are used on extracted water to increase the temperature to a suitable level for space heating and hot water that can be used in small and large buildings.

The interest in sustainable energy solutions is not only from governments, industry and households. In recent years, Europe has seen an increase in the number of energy cooperatives and energy communities, or collective citizen initiatives that seek social innovative solutions to bring affordable and sustainable energy to their communities. In this regard, energy communities play an important role in the energy transition process, as they bring the social innovation elements to technological innovations to ensure that these innovations meet social goals (Wolsink, 2012). In the case of aquathermal energy innovations, it is also important to ensure that this technology meets social needs, whereby energy communities and cooperatives could be the bridge that brings this technology closer to the people.

1.2. European Union policy ambitions

The European Union's *Fit for 55* package was presented by the European Commission in July 2021. It is the EU's target of reducing net greenhouse gas emissions by at least 55% by 2030 (Evans & Gabbatiss, 2021). According to the EU, the package of proposals aims at providing a coherent and balanced framework for reaching its climate objectives. This includes ensuring a just and socially fair transition, maintaining and strengthening innovation and competitiveness of EU industry, all while maintaining a strong focus on climate change mitigation. The Fit for 55 package is a set of proposals "to revise and update the EU legislation" and to ensure that EU policies are in line with the climate targets agreed by the EU Council and Parliament. Furthermore, there is also a longer commitment to reach climate neutrality by 2050. This is also accompanied by the commitment to have 40% of energy from renewable energy sources in the overall energy mix by 2030 (European Union, 2022). The package also lays out goals for heating and cooling where there is an increase in renewable energy use by 0.8% per year for each member state until 2026, with an increase in this percentage to 1.1% from 2026 to 2030 (Council for European Union, 2022).

The use of heat pumps for cooling and heating in Europe is regarded as a good strategy that will ensure a low-carbon energy transition and less reliance on fossil fuels while lowering thermal energy costs and meeting climate targets (IEA, 2022). Heat pumps are mechanical systems that transfer heat from cool spaces to warm spaces by moving thermal energy via a refrigeration cycle. They can transfer heat from, for example, outdoors to warm up a house. Conversely, pumps can also be designed to move heat from the house to the warmer outdoors in warmer weather. As they are designed to transfer heat, rather than generating heat, they are more energy efficient than other technologies in providing thermal comfort (U.S. Energy Dept. n.d.). There are many types of heat pumps (e.g., geothermal, air source, absorption) from small household systems to large pumps used for district heating. In Europe, heat pumps are seen as a leading technology to replace fossil fuel heating systems (Lowes et al., 2022). In 2017, approximately 83% of the EU's installed capacity for heating came from fossil fuel-fired systems using fuels such as natural gas (66%), coal (2%), and oil (15%), (Lowes et al., 2022). This is estimated to be a total of 129 million boilers, mostly inefficient and with C or lower energy ranking. Figure 1 illustrates the distribution of space heating installed capacity in the EU.

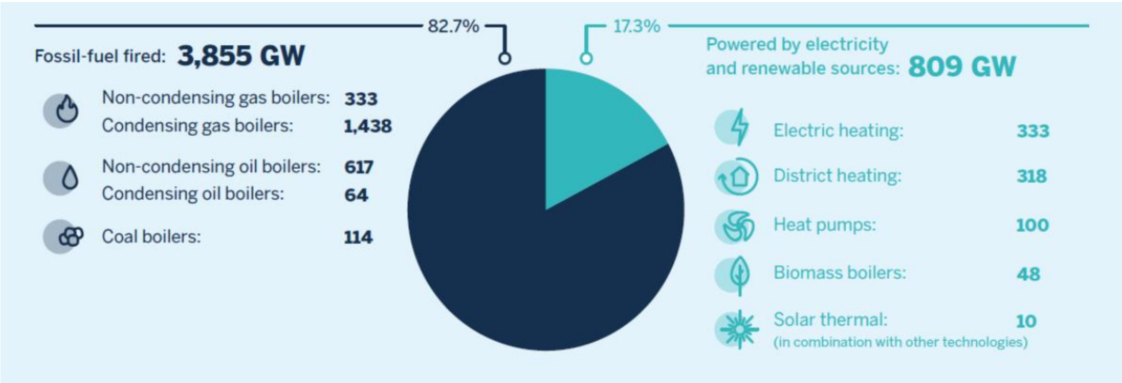

Figure 1: *Installed capacity of space heating in the EU in 2017. Source: Lowes et al. (2022).*

The IEA report of 2022 outlines several barriers that need to be overcome to enable adoption and wide use of heat pumps (IEA, 2022). Although the cost of heat pumps has been identified as the main barrier, this is associated with several other factors such as unsuitable fossil fuel systems infrastructure that is not easily adaptable to heat pump technologies (Lowes et al. 2022; IEA, 2022). The infrastructural changes are also associated with, for example, cost impediments and lack of uniformity in the heating network infrastructure across European countries (IEA, 2022). Moreover, the cost barriers are also linked to a lack of subsidies as previously enjoyed by existing technologies, including district and gas heating systems. In some EU countries, as a way to alleviate the effects of energy poverty, governments still allow and subsidise the installation and use of fossil-fuel heating systems (Lowes et al. 2022; IEA, 2022). There are also non-cost barriers that have been identified as possible hindrance to the adoption of use of heat pumps and related technologies. Lack of information by potential users and government regulations on technologies and building standards are also identified as barriers that hinder use of heat pumps.

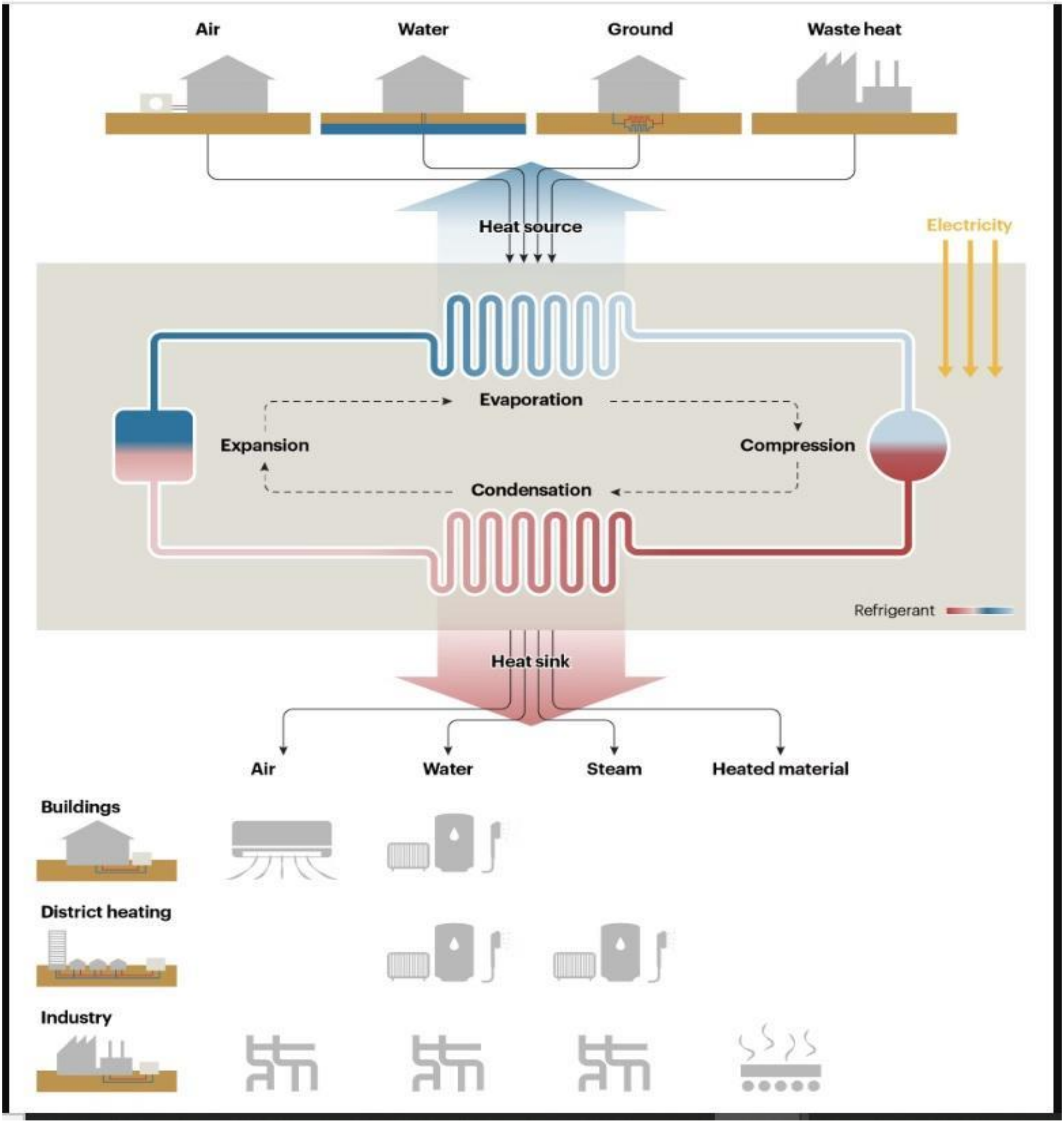

Figure 2: How a heat pump works. Source: IEA, 2022.

According to Lowes et al. (2022), the EU's 'Fit for 55' package also presents proposals on modifying legislation concerned with heat pump deployment, but the authors believe that this should be given more emphasis. The researchers also state that, in order to meet the 2030 decarbonization targets, the heat supplied by heat pumps in the EU must triple (2022:11). The growth of use of heat pumps is limited to some EU states, contributing a modest "2.5% of overall EU cooling and heating demand" (2022: 11). It has also been clear that for countries that have been successful in deploying heat pump technologies, there has been clearer strategies and policy stability, as well as a mix of different policy measures such as pricing mechanisms, financial support, and regulation (Lowes et al., 2022).

For the heat pump systems to be implemented as viable technology, the policy and regulatory measures in the EU must take into account the existing costs on fossil-fuel systems, and rebalance them with the costs of heat pumps to support building owners and residents. A policy package that would support heat pump system deployment in the EU should consider providing capital support for upfront costs, pricing policies that would discourage rise of running costs, use of regulations to drive purchasing behaviour and a governance framework to enable heat pump deployment (Lowes et al., 2022).

1.3. Aquathermal energy systems

Aquathermal Energy systems refer to the extraction, storage and distribution of thermal energy from drinking (TED), surface (TEO) or waste water (TEA) to cool and heat homes and other buildings (Benning, 2023; Goossens et al. 2021; STOWA, 2023). According to the *Netwerk Aquathermie* (NAT), *aquathermia* refers to the sustainable way of using water for thermal heating and cooling needs while simultaneously contributing to climate neutrality goals by lowering emissions and dependence on fossil fuels such as gas, coal, and oil.

AE systems are an under-explored type of heat pump technology in many parts of Europe. They can be viewed as an important part of deploying a heat pump technology transition in the EU as they are key in amplifying the energy from water sources to the high quality energy for warming and cooling purposes in buildings. In countries where there is experimentation with AE systems using different surface and waste water sources, there is also a consideration for policy and governance systems that will allow further implementation of these systems (Benning, 2023). According to NAT (2023), countries such as Norway, Sweden and Finland have an established practice of using AE systems, but there are very few of such projects because of low take up which is influenced by the availability of other energy sources such as hydropower and biomass, as well as high costs associated with the implementation of AE projects. The countries with the most AE systems projects are said to be Switzerland and the Netherlands (Benning, 2023). In the Netherlands, several stakeholders including government, water boards, commercial and investment groups have signed a 'Green Deal Aquathermie', to work together in finding solutions for governance, large scale investment and implementation of AE projects (Green Deals, 2019). The NAT report lists three large scale AE projects that have been implemented in the Netherlands. Thermo Bello (TED); De Veldkamp swimming pool (TEA); Merwerhoofd (TEO).

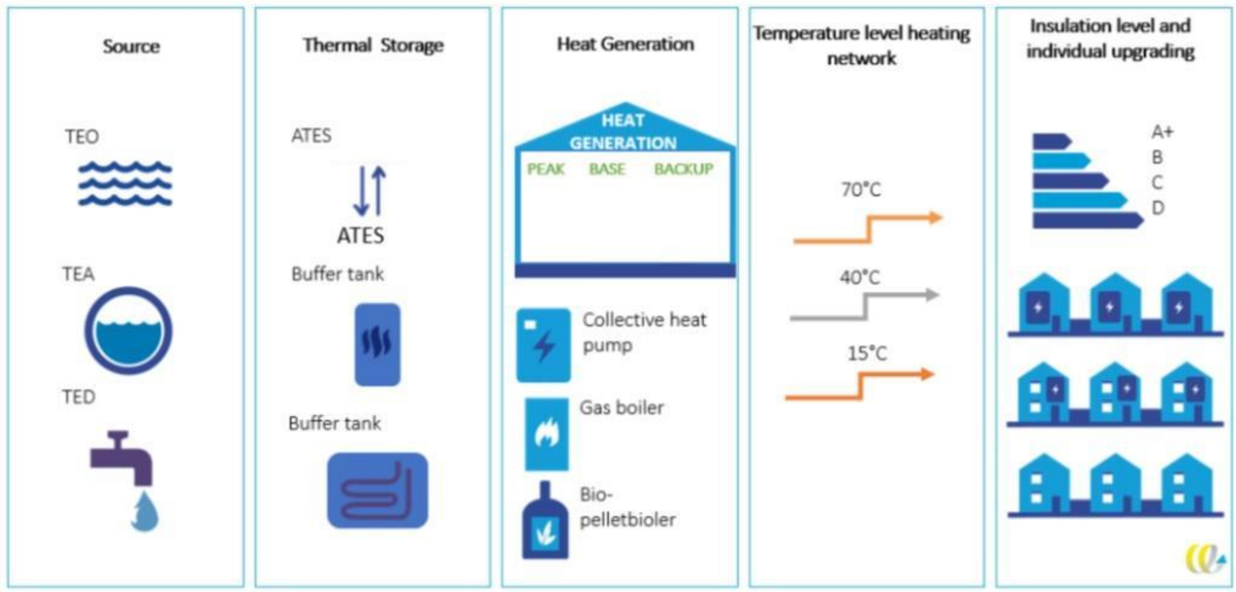

Figure 3: *Graphic depiction of AE system. Source: CE Delft and Syntraal (cited in NAT, 2023).*

1.4. Problem definition and research questions

Despite being a promising technology, AE systems have thus far only been installed to a limited degree, creating knowledge gaps on 'why' on the low uptake of this technology. We deem gaining an understanding of AE systems necessary as well as learning about current research, experimenting with and scaling of AE system innovations. In this report we view AE systems as a sustainable and technological system innovation with potential high environmental and economic impact. Therefore, we take an interest in AE system innovation niche development, whilst also focusing on intervention, transition management and governance to stimulate further uptake. We subdivide the AE system niche into heating and cooling systems.

The aim of this report is to contribute to sustainable energy system innovations and transitions in the EU, in particular that of AE. This report is part of the Interreg North Sea II WaterWarmth project. This project develops pilots and examples that show the potential of AE. The aim of the project is that actors from private, public and civic sectors adopt and implement joint strategies and action plans during or after the project. More concretely, the objective of this report is to present a literature study of relevant theoretical and analytical frameworks available to analyse the governance of current heating systems and future energy system innovation, in particular with regard to AE systems. Based on collective research efforts within the context of this Interreg North Sea II WaterWarmth project, we present a number of theoretical approaches to understand and better guide AE system transitions. These approaches include the multi-level perspective (MLP), strategic niche management (SNM), contextual interaction theory (CIT), Governance of Change (GoC), Governance Arrangements (GA) and Community Energy Systems (CES). Jointly, the frameworks create a comprehensive platform for researchers, users, and practitioners to comprehend and assess renewable energy transition processes, and more specifically, pathways for how AE systems can play a more significant role in a renewable energy system transition in the North Sea Region and beyond. Furthermore, we augment the approach presentation with a discussion on energy governance, from the perspective of governance of change to more tangible community energy systems to drive the change.

The central research questions addressed in the report are:

- How can we understand an AE transition in the EU in broader theoretical perspectives addressing sustainability transitions and governing change?
- Which theoretical frameworks can be used to analyse transformative change and governance in practical AE cases?
- In what ways can theoretical frameworks be used in practical cases?

1.5. Approach and outline

The basis of the report entails a broad survey of both the academic and grey literature by project researchers on ways to conceptualise the greater use of AE systems in the EU. We present transitions as an overarching concept and the MLP and SNM as two useful perspectives that are apt for conceptualising and to help guide AE systems and other relevant heating and cooling energy system transitions down tangible trajectories. We then explore the governance perspectives that surround the system change with a focus on transition processes using community energy, with a special concentration on CIT. Subsequently, we assess two existing cases, one in Sweden and the other in the Netherlands, from a transitions perspective to demonstrate how we can understand AE developments and sustainable energy change from broader contexts. Finally, we synthesise and reflect on each of the cases and draw broader insights on how we can effectively conceptualise and further promote AE system development.

Chapter 2. Theoretical frameworks

This chapter presents a number of theoretical frameworks that can be useful to understand what governing a sustainable transition towards greater adoption of AE systems is about. These theoretical frameworks have different disciplinary backgrounds. Whereas the Multi-Level perspective (MLP) and Strategic Niche Management (SNM) have a background in Sustainable Innovation and Transitions (part of Science-and Technology Systems - STS), the Contextual Interaction Theory (CIT) and Governance Arrangements (GA) have a disciplinary background in governance and policy studies (each rooting in political science). Another theoretical framework, the Governance of Change (GoC) has a disciplinary background in both (although it leans a bit more to STS). Finally, attention is paid to Community Energy (CE) and Community Energy Systems (CES), each having theoretical frameworks of their own - for the reason that energy communities are important emerging actors that add value to AE system development, and influence the social and institutional context in which AE is planned and implemented. It should be noted that the emphasis in this report - hence this chapter - is on MLP, SNM and CIT. These three are considered the primary theoretical frameworks. The other theoretical frameworks are also considered important, but are more of secondary nature in this work.

This chapter provides an introduction to each of the theoretical frameworks mentioned (Sections 2.2-2.4, 2.6-2.9). In addition, attention is also paid to the way MLP, SNM and CIT complement each other (Section 2.5).

2.1. Sustainable innovation and transitions

Transitions serve as a strong theoretical foundation for how to view AE system development. Transitions are a nonlinear shift from one dynamic equilibrium to another (Loorbach et al., 2017, p. 600). More specifically, sustainability transitions are the large-scale societal changes, deemed necessary to solve large societal challenges, including climate change, biodiversity loss, and the change to new forms of energy conversion, including heating and cooling, that are less-impactful (*Ibid*.). Transitions do not take place easily, since existing systems are characterised by stability and lock-in (Verbong and Geels, 2010).

Transitions as a research field is an inter- and transdisciplinary arena that emerged from multiple directions since the 1990s, making it a concept as well as a set of research streams to address large societal change and sustainability (van den Bergh et al. 2011). Research in the field aims to foster a better understanding of the human and technical system dynamics in the transition process and how more effective analytical tools and governance strategies can be devised to promote sustainable change processes. Transitions scholarship advocates that governance is a multi-actor process where broad solutions, disruptive innovations, and (reflexive) institutions are formed through experimentation and participant learning. The governance approaches aim to stimulate and traverse complex processes of a socio-technical system through actor deliberation, scenario creation and analyses, experimentation and learning (Grin et al., 2011). Furthermore, there is emphasis on interactions between different facets of society, especially through the creation of real-world experiments (e.g., pilots, demonstration projects), where new socio-technical configurations can grow and conditions for their amplification can be studied and replicated (Van den Bergh et al., 2011).

2.2. Multi-Level Perspective

The Multi-Level Perspective (MLP) is a framework commonly used in socio-technical transitions research (Geels, 2002). It is used to study, understand and explain transition to new socio-technical regimes (e.g., from a natural gas-based heating regime to a heating system using renewable energy sources). MLP assumes that transitions are caused by interdynamics between three strategic levels in which change takes place. They pertain to: (1) the socio-technical landscape (macro level); (2) the socio-technical regime (meso level), and (3) the niche, which is home to radical innovations (micro level). MLP holds that socio-technical transitions (including sustainability transitions) are the outcome of multi-dimensional interactions between the three levels (Verbong and Geels, 2010). Socio-technical change occurs following the process which contains: (1) the landscape level exerting pressure on socio-technical regimes, whilst (2) externally, positively influencing innovation development at the niche level; with (3) a selection and nurturing process at the niche level leading to establishing a dominant niche innovation design; (4) that enters and breaks through the incumbent regime; (5) eventually replacing the current regime; and (6) influencing the socio-technical landscape (Geels, 2002; 2011).

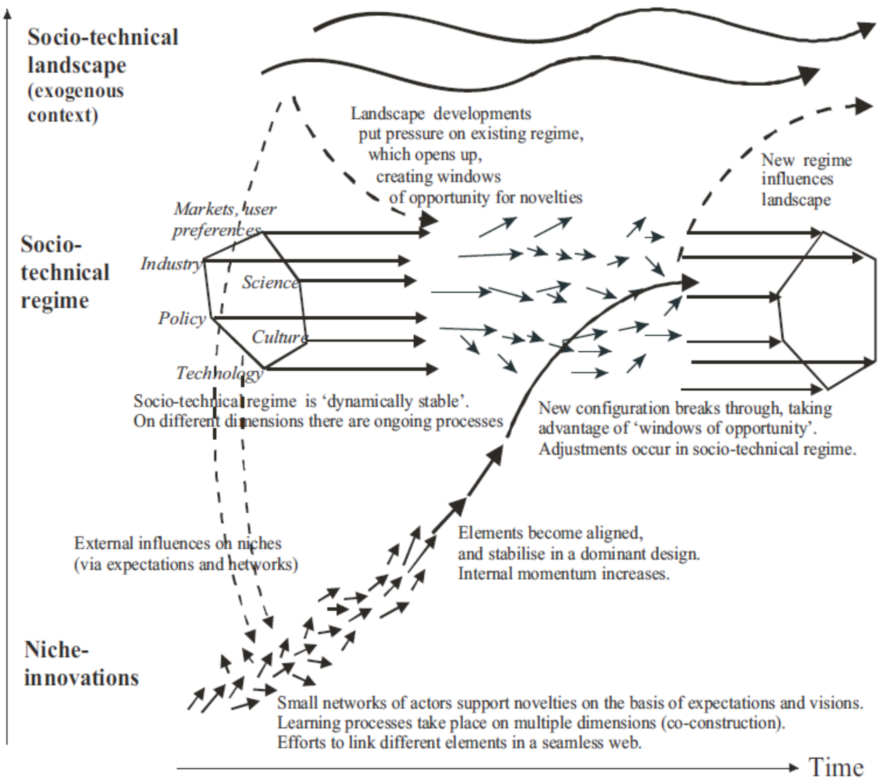

Figure 4: *Multi-level perspective on transitions. Source: Geels (2011).*

Socio-technical landscape (macro level)

The (socio-technical) landscape forms an exogenous environment which entails the wider environment surrounding the niche and socio-technical regime. It goes beyond the direct influence of niche and regime actors. At the landscape level so-called 'landscape events' occur. They pertain to include macro-economic developments (like economic recessions, crises caused by price cartels that have global impact), deep cultural patterns, macro geo-political developments like wars, major environmental disasters like Chernobyl in 1986 (Geels and Schot, 2007) or Fukushima in 2011, or the European Union setting new goals and implementing new directives (that require EU member states to transpose them in national legislation). Other examples of landscape concepts can include, but are not limited to neoliberalism, capitalism, geo-political developments, eco-modernity, the UN's Sustainable Development Goals, or resilience thinking to name a few. Landscape events have global impact, crossing national borders. Landscape events typically have a high level of abstraction (e.g., supra- or international), they are major exogenous events and factors that take place and may severely impact socio-technical regimes by exerting pressure on them, albeit often slowly. Moreover, landscape events provide an impetus for innovation development and experimentation at the niche level. However, landscape events can also reinforce regimes, where they have stabilising effects, and do not serve as drivers for change. Conversely, there are landscape events that have a disruptive nature whilst exerting pressure on socio-technical regimes, creating impulses for change (Geels and Schot, 2007). Whereas the landscape level typically plays out beyond the national level with major exogenous factors generating global impact, the niche and regime levels are often found at the national level.

Socio-technical regimes (meso level)

The socio-technical regime (meso level) is central to MLP theorisation. It represents the socio-technical environment of currently used, traditional technologies that are dominant (like the natural gas system in domestic heating). A socio-technical regime refers to an established system of technologies, infrastructure, legislation and markets that support the current modus operandi. It is coordinated by a set of partially coherent rules that guide transactions between (incumbent) actors who have an interest in maintaining the status quo (Geels, 2002; 2011). Socio-technical regimes are characterised by path dependence and 'lock-in'; they can be seen as stabilising mechanisms that evolve incrementally and are of rather static nature. Typical regime characteristics pertain to vested interests, sunk investments, existing and stable beliefs (Geels, 2005). A socio-technical regime is characterised by six dimensions - or interrelated 'sub regimes' - that include: (sectoral) policy, infrastructure/technology, market/end users preferences, industry, cultural beliefs, and science that surround a traditional, dominant technology. Several incumbent actors have vested interests in maintaining the status quo, and they often work together to prevent the current socio-technical regime from changing. They use their agency to deter radical innovations that seek to replace and terminate the current regime in place. Instead, incumbents seek to incrementally innovate regimes. Regimes are characterised as stable systems that are resistant to change. However, in practice, regimes and the actors that are part of them may not be all that resistant to change, or opposed to (radical) innovation, as regime players are also observed, for example partaking in partnerships that empower renewable community energy projects (De Bakker et al., 2020).

Niche (micro level)

The niche (micro level) serves as a temporary protected environment for the nurturing, selection and development of innovations that may have the potential to radically change current regimes (Geels, 2004). A niche functions as an 'incubation space' and usually arises from government subsidies or a strategic investment by companies (Geels, 2002, 2004). It is at the niche level where innovations emerge and mature. The protected environment (shielding innovation from market and regime forces) provides conditions that contribute to experimenting, improving and scaling innovation, after (several iterations) an innovation becomes competitive under the conditions present in the current established regime (Smith & Raven, 2012). A niche consists of actors who push innovation, are active in experimentation, and would like the innovation to develop, mature and eventually replace a current regime. This innovation process can be managed in an intentional way. This is what is referred to as 'Strategic Niche Management'.

X-Curve metaphor and tool

In the MLP transitions occur emphasising interdynamics between the three conceptual levels. One of the tenets addresses destabilisation and gradual breakdown of (often unsustainable) socio-technical regimes, which allows a niche to develop into the regime and eventually replace it. In this sense, transitions do not only focus on niche development, but also assume regime breakdown. When you present these processes in a time dimension, this results in an X-Curve, so to speak. With on the one hand a curve that tends from high to low (regime) and on the other hand a curve that goes from low to high (niche). This curve can help analysts and policymakers consider what it will take to pursue transformative change. On the one hand, this is about niche development (see also the next section about Strategic Niche Management, but on the other hand, it is about (gradually) abolishing or even terminating policies and other measures that maintain current unsustainable regimes. Consider, for example, the systematic phasing out of subsidies for fossil fuels.

One way to apply the X-Curve is in developing common understanding in the ways regime factors impede transformative change and the ways niche factors enable transformative change. This can be applied to researchers or policy makers in an individual way, but it can also take place in a wider setting engaging stakeholders or citizens in the system analysis and co-design of a given transition, using co-creative workshops. Here, one may consider using the X-Curve (Silvestri, Diercks and Matti., 2022), a visual tool. This co-creation tool aims to create an understanding of the transition dynamics into a given socio technical regime (like gas-fired heating systems) in a given country, city or other jurisdiction, aiming to explore (different) transition dynamics, whilst co-designing possible transition pathways, guided by imaginable ways to phase out unsustainable regimes, whilst encouraging sustainable niches. In the case of planning for and implementation of AE systems, this tool could for example be used to gain understanding in the governance and adoption of AE systems. Here, the tool can be used for “system mapping, priority setting and governance, instrument mix and experiments, and learning and institutional change” (Silvestri et al. 2022: p.10). A practical example of a case in which the X-Curve tool has been applied is the City of Mechelen. In 2022 the local government invited stakeholders and civil servants to participate in a Transition Arena, using this tool to co-assess the current system and co-design the local heat transition. After a stepwise process including three workshops, X-Curve transition pathways were co-designed. This laid the foundation for municipal policy in the field of heat transition (Manktelow et al., 2023).

2.3. Strategic Niche Management

SNM can be seen as an approach to support and help ensure niche level innovations develop and mature (Hoogma et al., 1998). It promotes aligning social (e.g., institutions, policies) and technical systems (e.g., energy technologies). SNM was developed to understand the emergence and diffusion of innovations. SNM looks at how innovations can evolve through sets of experiments. Experiments refer to (local) projects in which one can learn about the characteristics and performance of a given niche innovation (Weber et al., 1999). SNM consists of three internal processes to manage niche innovation. They pertain to: 1) Voicing and shaping of expectations; 2) Network formation; 3) Learning processes. Table 1 presents a detailed overview of the three internal niche processes of SNM.

Voicing and shaping expectation refers to expressing and moulding expectations. This involves the participation of various actors, including firms, users, policy makers, entrepreneurs, and other relevant stakeholders, who contribute their expectations to the project. It is crucial to articulate these expectations as it helps to garner attention, resources, and new actors to the project. This is particularly vital during the initial stages of technology development, when the innovation’s functionality and performance may still be indeterminate. By voicing and moulding expectations, niche projects can establish a shared vision and gain support for innovation (Raven, 2007).

The second niche internal process entails network formation. During the early phases of an innovation’s life cycle, the social network supporting it is often fragile and needs to be nurtured. Experimentation in niche markets allows different actors to come together and form new social networks. These networks are vital in knowledge exchange, collaboration, and resource mobilisation. They facilitate learning, trust-building, and sharing experiences among actors involved in the niche, ultimately enhancing chances of successful innovation (Smith et al., 2005).

SNM holds that learning is imperative for successful innovation as it allows for the customization of technology and its societal embedding. Learning by doing and experimenting in a local project context is critical in the case of "configurational technologies, "such as energy technologies, where multiple components have to work together effectively. By following this process, actors within the niche gain valuable insights, acquire technical know-how, and refine the innovation to increase its chances of successful diffusion (Van der Laak et al., 2007).

***Table 1 -** The three niche processes and their indicators table - Adapted from Kamp and Vanheule (2015)*

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

2.4. Contextual Interaction Theory

The basic assumption of CIT is that “the course and outcomes of the policy process depend not only on the inputs (characteristics of policy instruments), but more crucially on the three core characteristics of the actors involved in the transition process, particularly their motivation, interaction, and power” (Bressers 2004). The use of these core actor characteristics is that they are recognised as critically explanatory variables regarding implementation processes. The emphasis of CIT lies on social interactions among actors and how they influence policy processes (in particular implementation) that are determined by actors and their core characteristics (Bressers 2004, 2009).

CIT further acknowledges that policy formulation and implementation are interaction processes, and that motivation, information and power (as actors’ core characteristics) provide a critical explanation. CIT assumes that policy implementation processes are not only about achieving policy goals, but also about attempts to prevent implementation or to change the character of what is implemented.

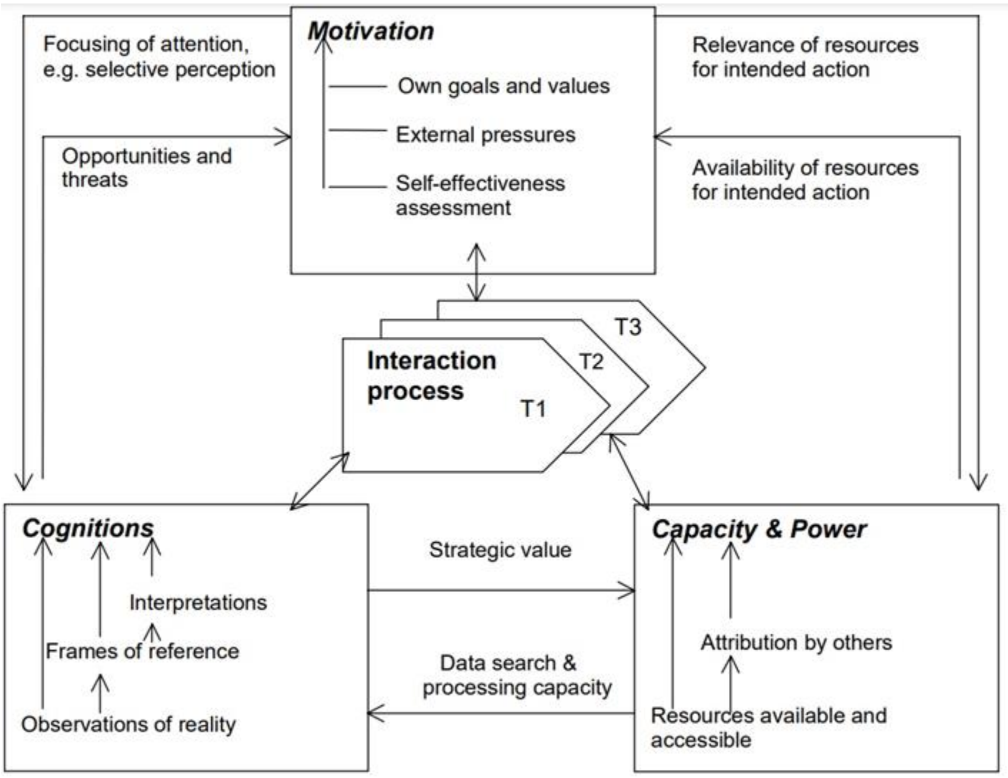

***Figure 5**: Dynamic interaction between the key actor characteristics that drive interaction processes. Source: Bressers (2007).*

CIT considers that the three actor characteristics are "not only central to the actors and influenced by the process, but are also influenced by many external factors from a multi-layered context" (De Boer, 2012: 28), namely the specific, structural and wider contexts.The specific context is concerned with specific case or project circumstances and their influence on the interaction or implementation process. The structural context considers the influence of governance, including institutions, actor networks, policy mixes and instruments. Finally, the wider context is concerned with global political, economic and cultural factors influencing the interaction and implementation processes (Bressers 2004, 2009).

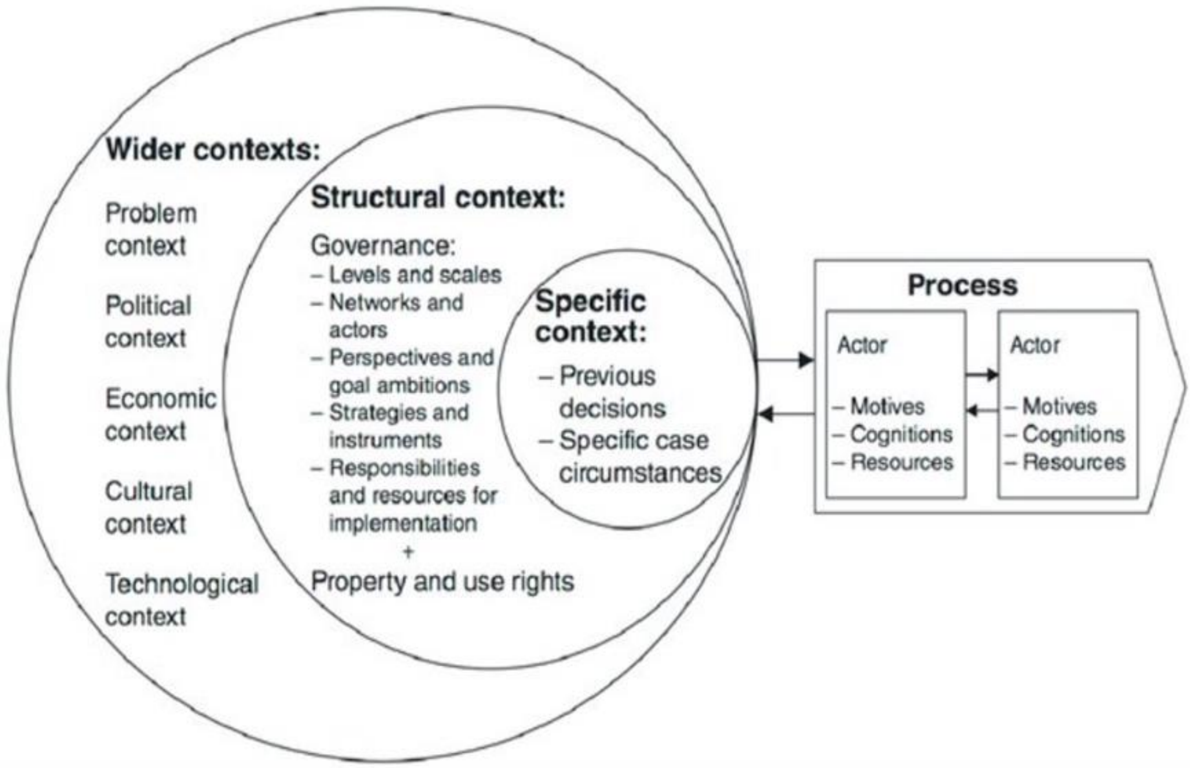

Figure 6: *Layers of contextual factors for actor characteristics (Bressers, 2007).*

Table 2 below provides operational definitions that are used to provide meaning to the concepts used in CIT.

Variables and concepts	Operational definitions
Motivations	- Focusing on the reasons behind the actor's participation in an interaction (implementation) process. - Sources of motivation include: own motivation, external pressure and self-effectiveness assessment.
Cognitions	- Refers to information processing capacity held by an actor and how this contributes to the interaction process. - How the actor's interpretation of reality (situation) influences the interaction process. - How information and knowledge about the context and other actors influences the interaction process.
Resources and power	- What resources do actors have access to and how this influences the interaction process. - How resources influence power relations and power attribution between actors
Specific context	- How do case or project specific circumstances influence the interaction process
Structural context	- How the levels and scales of governance, networks and strategies influence the interaction process.
Wider context	- How political, economic and cultural contexts influence the interaction and implementation processes

Table 2: *Operational definitions of concepts used in CIT application. Adapted from: Bressers (2009) and Mohlakoana (2014)*

In the case of technological niches such as AE systems, policies that govern the implementation of such technologies are important. Also important is how different actors interact in the formulation and implementation of such policies. We can therefore use the CIT to analyse the influence of actors (i.e., in both socio-technical niche and regime level) in promoting technological niches and the ways contextual factors influence these interactions.

Motivations and public perceptions are important in driving AE projects (Van de Witte, 2023). The motivation to install AE systems can be linked to high natural gas prices that the government and public want to avoid both for climate considerations and costs. Public perceptions can be linked to 'cognitions' in CIT. Based on the interviews conducted by Van de Witte (2023), it is clear that public perceptions can influence motivations. In this case, a number of stakeholders were supportive of the installation and use of AE systems because low temperature in canals may lead to the return of the 'Elfstedentocht', a skating event on frozen canals which has not taken place since 1997 due to unfavourable warm temperatures in winter.

2.5. Complementary elements from MLP, SNM and CIT

It is clear that the MLP, SNM, and CIT are relevant to use in analysing the governance and implementation aspects of adopting AE systems. Figure 7 below presents a graphical combination of MLP, SNM and CIT to illustrate how they can be used in a collaborative manner to explore the intricate details of how AE projects have been implemented taking into account the governance, regulations, the actors involved, as well as innovation-transition dynamics. CIT complements MLP and SNM mostly in addressing agency in local, regional policy processes and implementation projects (e.g., with experimental AE application). This not only focuses on the niche level but also addresses interaction between the niche and regime levels (i.e., between innovative niche actors and regime incumbents). Moreover, the CIT's wider context resembles the MLP's landscape level, the CIT's structural context resembles the MLP's socio-technical regime level, and the CIT's specific context resembles MLP' and SNM's local context in which innovation and transition experiments take place. The CIT's dynamic interaction process addresses an action situation (where actors meet and interact, and where decision-making takes place) which can be situated in such experimental regional and local projects. However, this can in theory also apply to implementation of renewable energy policies at the national level, and can be used to evaluate implementation of these policies in nation states like Sweden or The Netherlands. These insights will assist in mapping the way forward on how such an integrated framework can provide some insight for future implementation of AE projects.

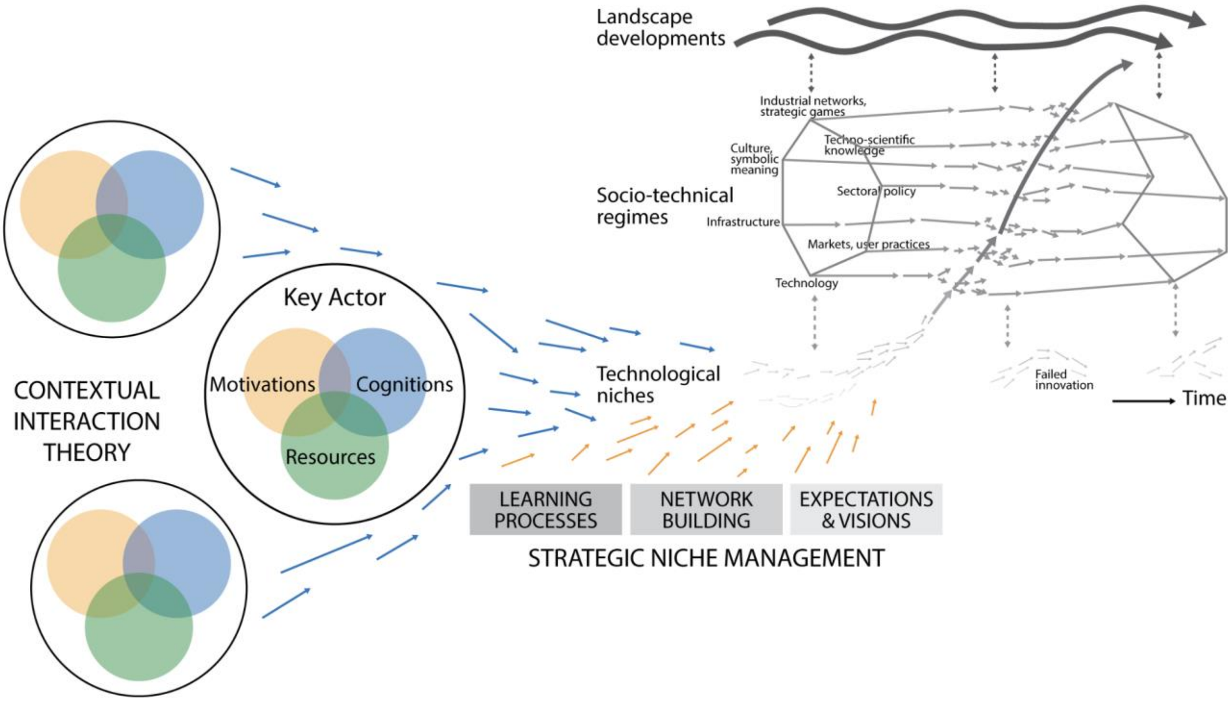

Figure 7: *Graphical overview on how CIT, MLP and SNM can be used to complement each other. Adapted from: Bressers (2007); Geels (2011) and Kamp and Vanheule (2015).*

2.6. Governance of change

Borras and Edler (2014) developed a theoretical perspective addressing governing change in (unsustainable) regimes. The perspective helps to address questions like how system change is coordinated in complex contexts, more particularly what are the modes and actors of coordination? In other words, the way in which societal and state actors intentionally and deliberately interact in order to transform socio-technical systems. Like MLP and SNM, the governance of change adopts a systems perspective. To understand the governance of change Borras and Edler (2014) discern three 'pillars': (1) opportunity structures and capable agents; (2) governance and instrumentation, and (3) legitimacy and the process of governing change. If change of a sociotechnical regime is to take place there have to be beneficial conditions supporting change in each of the three pillars (as necessary conditions).

Opportunity structures and capable agents refer to the co-evolution of technology and social institutions, which sequentially or simultaneously generate opportunities for change to agents (i.e., societal actors). This requires the presence of actors who are capable of triggering or directing change by capitalising new opportunities (i.e., agency, 'policy entrepreneurs'; 'change agents'). Here, the focus is not just on technology but rather on its embeddedness in the wider socio-technical regime, and more specifically on social institutions (i.e., 'rules of the game'). Opportunity structures offer new knowledge and potential in relation to possibilities that help solving problems or granting new venues for social interaction. Furthermore, Borras and Edler (2014) assume that governance entails negotiation and bargaining between interested state and non-state actors, with actors exercising power throughout these negotiations. Here, key questions pertain to who are the primary agents of change, what is their capacity to induce or inhibit change, what capabilities do they have (i.e., resources and interpretative abilities), and what is the distribution of the agents' capabilities within the larger system/regime?

Governance and instrumentation address issues on how change is influenced. Governance instruments refer to a generic concept addressing different possible types of instrumentation in the process of inducing change. They discern two types of instruments: (1) 'policy instruments' designed and implemented primarily by 'state agents'; and (2) 'social agent's instruments' which are designed and used by non-state agents. Borras and Edler (2014) furthermore discern traditional policy instruments (i.e., the 'carrot, stick, and sermon') like regulation and economic incentives from STS instruments like constructive technology assessment, innovation policy or 'sandbox' experimentation schemes. They deem the latter category necessary to induce system change. Relying solely on traditional policy instruments does not suffice to trigger change. Key questions regarding the second pillar include who is/are designing, shaping and using the instruments, how are instruments shaped and by whom (pursuing which agenda), how are those instruments put into practice and implemented, and what are the results/impact when implementing these instruments.

And finally, *legitimacy and the process of governing change* pertain to views and support of a given socio-technical system (or lack thereof; i.e., the social dimension of legitimacy), and to the process of governing change (Borras and Edler, 2014). This addresses acceptance of a given innovation or transformative project or approach, and the resulting system change (and evaluation thereof). It assumes that socio-technical regimes are legitimate if they enjoy wide social acceptance and support. However, the process of governing change must also be considered legitimate by societal actors. In other words, regimes are (only) considered legitimate if they enjoy popular support, both in terms of the process by which the decisions are taken (also referred to as 'input legitimacy') and in terms of the support of the system's outcomes ('output legitimacy'). Whereas the former form of legitimacy addresses fairness of the process the latter focuses on the 'success' that governance delivers, the effectiveness to solve problems and to achieve what is perceived as being in line with main societal preferences (*Ibid.*).

2.7. Governance arrangements

The question can be raised about how to develop governance arrangements (GA) that contribute to governing change (e.g., in transforming fossil fuel based heating systems into sustainable heat systems using AE technology). This goes further than adopting a mere focus on hierarchic and monocentric approaches to governing energy transitions, and formulating appropriate (traditional) economic and regulatory policy instruments that support them. In fact, such an approach to governing would only suffice when dealing with simple structured problems that can be resolved with straightforward solutions, like when constructing new homes, implementing a permit system to safeguard housing qualities (for example, on safety, structure, pricing, energy and sustainability standards). In reality, - especially when dealing with grand societal issues like energy transitions - more comprehensive, radical governing approaches are required that assume complex, unstructured problems, i.e., societal problems that are characterised by a high degree of uncertainty and contested knowledge, and the presence of multiple stakeholders holding a multitude of often opposing views and (public) values. The latter typically applies to environmental issues like climate change, circular economy, and sustainable energy transition. Termeer et al. (2017) developed a framework to further understanding in governance arrangements that are designed to cope with unstructured problems. We propose that experimenting, scaling and future governing of collective AE systems falls within this category. Typically, new governance arrangements addressing sustainability issues and/or transformative change in society face tensions with existing institutions, and interests of incumbents. Acknowledging the political nature of governance, these governance arrangements should be seen as emergent outcomes of complex political processes, instead of mere rational designs by 'scientific' and assumably 'rational' policy makers and engineers.

Termeer et al. (2017) discern a series of seven basic core elements that belong to said governance arrangements: (1) the framing of the problem; (2) the (territorial) governance levels at which to act; (3) alignment across sectoral boundaries; (4) the timing of policies; (5) the selection of policy instruments; (6) the organisation of the science policy interface; and (7) appropriate forms of leadership.

(1) Problem framing refers to how actors view a problem or societal issue. This has to do with the specific problem feature of uncertainties and contested knowledge. Different actors or groups in society may view a problem in different ways, applying different 'lenses' to them (often the one that fits their interests, experiences, ideology or political narrative). The process of framing involves an interplay between 'puzzling' —to develop and negotiate plausible storylines and solutions—on the one hand and 'powering' on the other —to decide whose frames are most relevant, using tough bargaining measures, and the exercise of power. Organising room to reflect (i.e., reflexivity), is considered important to appreciate and deal with the very existence of different (often pluriform) frames held by different actors and groups in society (Hoppe, 2011).

(2) Governance levels refer to the territorial levels where the right fit is found between the scale of a problem and the scale at which it is governed (e.g., between the local and the national level; Cash et al., 2003). Addressing cross-level issues and enhancing a vertical interplay between different levels of governance is considered crucial (Young, 2002). This requires a need for connection across scales (i.e., between the local, regional, provincial, national, and EU level), also to address alignment of strategy and coordinated actions. This is of particular importance to coordinated efforts in strategic niche action between several local experiments, and actions that support scaling to the regional level, and across regional or provincial jurisdictions.

(3) Alignment across sectoral boundaries refers to the challenge that governance systems deal with issues - like collective heating - that are highly fragmented across different policy and sectoral domains (like for example, water, energy, environment, spatial affairs, housing, safety, soil and nature preservation), whereas collective aquathermal

heat systems can be seen as a typical cross-cutting policy issue. Here, attention should be paid to address lack of inter-policy connections, which are not limited to the policymaking process, but should also address implementation practices (Dupuis and Knoepfel, 2013). To address cross-sectoral challenges, involvement of ‘boundary workers/spanners’ is necessary. This refers to actors who are experienced in multiple policy domains (i.e., regimes), being aware of their specific institutions and speaking their jargon, whilst having the ability to cross boundaries, supporting mono-sectoral policy workers to join in cross-sectoral challenges. Another approach to cope with inter-sectoral issues is process management – deploying collaborative governance - to strategically guide and direct multi-actors decision-making rounds, which support cross-boundary interaction to develop multi-functional plans, and encourage collective action in siloed policy domains.

(4) Timing of policies refers to when and in what sequence to act. Whereas responses that are too late may cause problems, (too) early responses may be problematic as well, risking (regime) lock-ins. Timing of policies is critical in light of political events, like local, provincial or national elections. To prevent lock-ins or regrets, researchers suggest robustness and flexibility as design principles to enhance resilience (Haasnoot et al., 2013). Robust measures refer to interventions that maintain performance under a different range of plausible future scenarios. Flexible strategies on the other hand, enable intensification or adjustment of measures when needed, which allows for adaptation to new developments or knowledge over time (Dewulf and Termeer, 2015).

(5) Selection of policy instruments refers to selecting public interventions that aim to influence the behaviour of specific target groups in society – like citizens or firms - in a certain direction, like towards adopting aqua thermal energy application or investing in aquathermal energy systems so that they can be installed and operated bringing certain benefits to local communities. Policy instruments are seldom selected and implemented in isolation. They typically come in ‘packages’ or are part of certain ‘policy mixes’ (e.g., combinations of policy instruments as well other key policy elements; Rogge and Reichardt, 2016). Context, structure (i.e., actor networks) and institutions greatly influence the ways policy instruments or mixes are selected and implemented, making policy instrument selection a highly politically sensitive process. When formulating policy mixes to support sustainable innovations like aquathermal energy systems, policy makers should pay attention that goals and instruments of policy align well, and are not just added to already existing (energy/heat) policies without careful consideration and coordination. If insufficient attention is paid to this aspect it may lead to mere ‘policy layering’ or ‘policy drifting’ (Kern and Howlett, 2009), rendering policy mixes ineffective in spurring sustainable innovation, or encouraging sustainable transition.

(6) Organisation of the science policy interface refers to carefully coordinating interaction between science actors on the one hand and policy actors on the other. Decision making in relation to sustainable energy transition in general and collective heat systems is knowledge intensive. Moreover, the relation between science and policy is complex (Boezeman et al., 2013). The traditional role of science as “speaking truth to power” is being transformed into an argumentative policy analysis as “making sense together” (Hoppe, 2011). Cash et al. (2003) suggest that scientific advice is only likely effective if relevant stakeholders perceive the knowledge as credible—meaning scientifically adequate, salient—meaning relevant and timely for decision makers, and legitimate—meaning acceptable to different stakeholders. Boundary organisations, joint fact-finding, and co-production are important notions for relating science and policy. Boundary organisations exist at the frontier of the two relatively different social worlds of politics and science, with definite lines of accountability to each. They involve actors from both sides and provide the opportunity for the creation of models or maps that help both parties to make sense of the situation (Guston, 2000). In innovation programs – for example to experiment with, scale and mainstream AE systems the science-policy interface - is of critical importance, and merits involvement of boundary organisations. However, politicisation of science on the one hand, and scientization of politics on the other should be avoided (*Ibid.*).

(7) Appropriate forms of leadership refer to government officials, elected politicians, and private sector actors all facing the challenge of enhancing coordination and cooperation across different problem frames, levels, sectors, time horizons, science-policy interfaces, and public-private spheres. In modern complex, polycentric systems there is a lack of actors who can act as 'leaders' with assumed traditional formal control over resources needed to design and implement interventions, or governance arrangements that go beyond the traditional, hierarchical conceptions of (single, traditional) leadership (Termeer et al., 2017). More recent leadership research points to complexity leadership, and more specifically four functions of leadership, i.e., administrative, adaptive, connective, and enabling (Meijerink and Stiller, 2013).

2.8. Community energy

One of the key goals of the Interreg North Sea II WaterWarmth project is to provide local energy communities with practical knowhow to integrate AE in their operations. AE systems are believed to benefit and empower local communities in multiple ways. Assuming the presence of beneficial contextual conditions like the presence of sufficient quantities of water and geophysical characteristics. However, AE systems can be adopted and implemented by multiple actors, like private sector project developers, municipalities, property owners (like social housing organisations or investors) or citizen collectives. At locations where there is a high degree of human capital mobilising resources and using concerted action to induce change to green heat systems the concept of 'community energy' applies.

Community energy – or collective citizen action in sustainable energy transitions - can be understood from a social innovation perspective. It pertains to organisations in which citizens are mobilised and collaborate to bring about sustainable energy transition, either at the local level, or even by changing current socio-technical energy systems and the institutions that go along with them (Hewitt et al., 2018). Community energy can also be understood as a variety of experiences of renewable energy development and provision, characterised by various degrees of public participation in project development (Magnani and Osti, 2016, p. 148). Goals of community energy initiatives are very varied, and include: installing renewable energy plants, energy savings or sobriety, solving energy poverty problems, making entire neighbourhoods or villages energy neutral, reaching energy democracy, and in general, contributing to the wellbeing of local communities. Community energy initiatives engage with low-carbon energy technologies either at the individual household-level (e.g., lighting bulbs, weather-strips, advice on energy-saving measures on appliances, water-use, heating, roof-based solar PV panels, insulation measures), or at the meso-level (collectively owned low-carbon energy installations (Walker and Cass, 2007), or district heating initiatives (Hoppe and Miedema, 2020; Itten, et al., 2020).

Whereas community energy comes in different organisational and legal forms (Walker, 2008) the most common and oldest form is the cooperative. The most common legal-organisational form of community energy organisation found across North-Western Europe is renewable energy supplying cooperatives, abbreviated to "REScoops" (REScoop.eu, 2016). The latter can be defined as groups of citizens who organise themselves to collectively take action to foster the use of renewable energy and increase energy efficiency (*Ibid.*). Cooperatives foster member involvement, democratic decision-making, and enable equal distribution of generated profits (Magnani and Osti, 2016; Hewitt et al., 2018). A cooperative is an autonomous association of voluntarily united persons to meet their common economic, social, and cultural needs and aspirations through a jointly-owned and democratically-controlled enterprise (Alliance, 2016). The legal entity is laid down in private law, and the exact form differs per country. REScoops do not necessarily require the legal statute of a cooperative, but rather distinguish themselves by the ways in which they handle their business (REScoop.eu, 2016).

The academic literature provides insight into how community energy collectives emerge, mature and professionalise. Boon and Dieperink (2014) developed a framework presenting enabling factors to this. They discern different factors as relevant for the emergence, growth, professionalisation, as well for their geographical diffusion and internal characterization. Warbroek et al. (2019) developed and empirically tested another framework, arguing that community energy collectives' success depend several (sub) conditions pertaining to the three core elements of (intra)organisational factors of the collective, interaction with the local community, and linkage to intermediaries and governance arrangements.

Whereas Boon and Dieperink (2014) and Warbroek et al. (2019) focus on frameworks presenting enabling factors Seebauer et al. (2022) present a 'maturity' model to energy collectives, describing a process of a number of stages through which collectives develop from emergence to maturity. Hoppe et al. (2023) adopted this model to develop a progress measurement framework which can be used to monitor performance and progress of energy collectives on selected indicators operating at different stages. These stages pertain to inspiration, preparation, implementation, and operation, as illustrated in Figure 8. For each of these stages, there are eight so-called thematic areas that call for attention in the development process, such as social (community), social (board and strategy), socio-demographic characteristics, organisation and strategy, financial, technical, policy and politics, and learning. The progress development framework (with in parallel developed tool) can be used to reflect and learn from organisational development of energy collectives, and support organisational design decision making. The Dutch federation of energy collectives, Energie Samen, in sync developed a stepwise organisational development 'methodology' (Energie Samen, 2023), which can help to set-up and professionalise local initiatives.

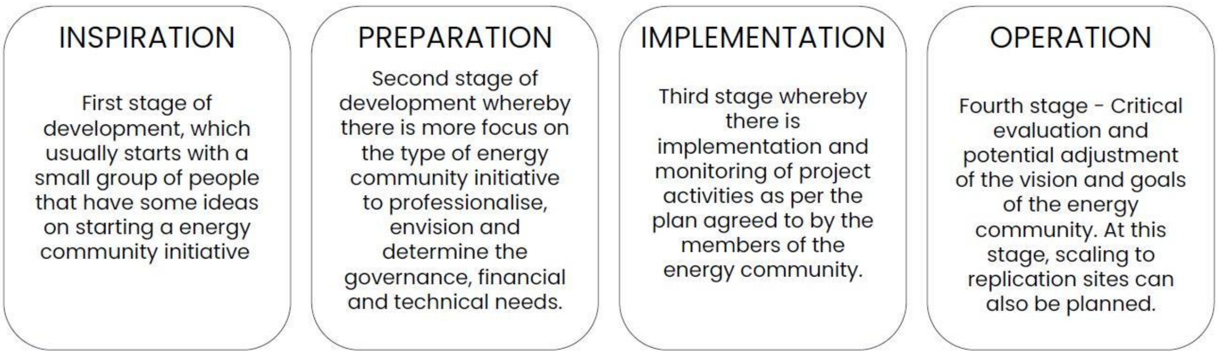

Figure 8. *Stages of maturity for energy communities. Adopted from: the SCCALE 203050 project - www.sccale203050.eu*

To understand how energy communities possibly engage with AE, and what their role can be in designing and implementing AE systems, it is important to understand how energy collectives are initiated, organised, legally embedded, and how they handle sustainable (including renewable) energy projects. Importantly, the projects, activities and operations enacted by a community energy collective of citizens are inevitably locally bound. The larger-sized renewable energy projects not only involve citizen collectives but also other stakeholders, often from the energy industry like distributed system operators, commercial project developers, property owners, and decentralised governments. In this case they plan and construct projects in partnerships (De Bakker et al., 2020).

2.9. Community Energy Systems

Increasing interest in local communities generating and supplying energy themselves has attracted attention of policymakers and project developers in implementing integrated local community energy systems. Next to adding a systems perspective to community energy (See Section 2.8 above) Community Energy Systems (CES) also pays attention to local communities being subjected to transformation, which includes challenging of traditional identities. For example, community members are not merely perceived as passive consumers but are viewed in a way that they become active ‘prosumers’ who both consume and produce local energy. Local communities are well-positioned to identify local energy needs, take proper initiatives and mobilise residents to achieve common goals like carbon reduction, energy savings, cost reductions, or dependence on increasingly unreliable high and medium voltage electricity grids. However, mobilisation of residents does not only contribute to technical and environmental goals but also to attaining socio-economic goals like local business and job creation (Koirala et al., 2016).

Taking these different dimensions into account there is a need to adopt a holistic perspective: integrated community energy systems (ICES). This can be perceived as a comprehensive and integrated approach for local energy systems where communities take (back) control of their local energy system and capture the benefits of different integration options (concerning numerous smart energy components like smart metres, virtual power plants, storage, energy hubs, and more). ICESs represent locally and collectively organised energy systems and combine the concept of CE, CES, smart grids (more particularly community micro-grids), and peer-to-peer energy trading *(Ibid.)*. In this sense, ICES can be viewed as the systems perspective to community energy employing smart grid technology options that enable local energy communities to take ownership of all local energy system’s assets, become independent – or even autark – from regional or national energy systems, become more resilient to system shocks such a national blackouts, whilst achieving environmental and local socio-economic goals. Moreover, ICESs are capable of effectively integrating energy systems through a variety of local generation of heat and electricity, flexible demand as well as energy storage. This may very well include AE heat options. ICESs do not necessarily only target local self-provision but may also provide system services to neighbouring systems such as balancing and ancillary services *(Ibid.)*.

Chapter 3. Case studies

To demonstrate the use of the approaches, two cases are focused on: household level AE system development in Sweden and AE transitions in the Fryslân region in the Netherlands. Although both cases are situated in EU member states, they are significantly different and are presented here to demonstrate applications of the approaches described in the report. The Swedish case is used to demonstrate the use of the MLP. The Dutch case is significantly used to demonstrate the use of CIT, governance arrangements, while also addressing a number of insights from MLP and SNM.

3.1. Case study 1: Household AE Development in Sweden

3.1.1. Case Background

Due to a set of unique circumstances, the development of AE in Sweden over the past decades has followed a unique path. Sweden constituted the largest heat pump market in Europe after a large-scale reorientation towards heat pumps from oil boilers and direct electric heating in the heating sector in the 1970s (Johansson 2021). Due to its geographical positioning, roughly one-quarter of Swedish energy use is in the form of heating. Furthermore, the heating sector uses approximately 100 TWh of energy, half of which is used for district heating, and which is largely supplying urban areas and smaller towns around the country, and the other half used for single-unit homes and small-scale heating (Fossil-free Sweden n.d.). In 2019, 1.2 million single-family homes, or 60%, used a heat pump (Swedish Energy Agency, n.d.), indicating heat pumps as a well-established technology and the potential for AE system development from this perspective.

Heating and cooling systems throughout the country are dominated by four main technologies: district heating, heat pumps including water and air, electrical heating, and biofuel boilers such as wood pellets (Dzebo and Nykvist 2017). The municipal district heating system development in the country got its start in the 1950s. Today, district heating is established in 285 of Sweden’s 290 municipalities, and consists of approximately 500 district heating systems throughout the country; large heat pumps are used in 28 of the district district heating systems (Werner 2017). Major heat sources used for these larger heat pumps have included treated sewage water, ambient water resources, and industrial excess heat. As for the roughly 1500 MW installed in total, the distribution breakdown is as follows: 13% for industrial excess heat, 27% for ambient water, 47% for sewage water, and 13% for other heat sources. The use of sewage and ambient waters have been more resilient, since the use of industrial excess heat has decreased considerably in recent years (Averfalk et al 2017). For example, the AE systems built by Stockholm Exergi in 1986 were constructed as a temporary solution as the electricity production became increasingly volatile. However, AE via heat pumps are now considered an essential part of the mix to balance the electricity grid (Tidningen Energi 2023).

AE can also be considered a viable option for detached household systems with the precondition of access to suitable water bodies and land ownership conditions. System collectors have also recently been evaluated for waste heat extraction from water bodies in abandoned mines as those can maintain a stable temperature between +8 degrees to +20 degrees, and hence could be another suitable heat source extracted using heat exchangers or collectors (e.g., Glas 2023).

3.1.2. Multi-level Perspective

The Niche

Despite the diversity of heating and cooling systems in Sweden, including centralised and detached household systems, the niche development we focus on for this case study is household AE system development. This can include single family homes or connected homes (e.g., townhouses). Centralised district heating using AE technologies could have been another focus, as it is also a popular form of heating throughout the country. However, we argue that the development of these large scale systems are less relevant for much of the other system developments for single buildings or more local heating networks in other EU countries. Therefore, our framing will focus on household AE heating system development.

Sweden has an extended history of household heat pump systems developments over the past decades with an increased interest over the last twenty years. Domestic heat pumps draw heat from the air, ventilation air, rock, ground, groundwater or lake water (Swedish Energy Agency n.d.). In addition to popular air sourced pump systems for dwellings (without water radiators), ground source (geothermal) systems are a common technological choice among Swedish consumers. Less widespread in comparison, are AE systems. An example of a niche level development can be found below in Box 1.

Despite many functioning household AE systems throughout the country, and AE being a well-tested and cost-effective technology, there is little compiled information and a deficiency of available statistics on the niche AE development from past decades. About twenty reports on mainly technological and resource aspects of AE in Swedish were found through a database search from the first half of the 1980s; however, the information has since been scant. In this report, our understanding of household AE development is mainly based on our interactions with a selection of different actors active in this arena, including private sector system installers, dwelling owners, and with existing Swedish online information sources on AE systems. Furthermore, as the "first phase" of AE installations took place in the early-1980s, we were not able to interview actors driving these early initiatives to further explore the network constellations and learning processes involved with early AE developments. Therefore, this has hampered our ability to gain a better understanding of SNM and CIT aspects for our cases, especially from a longer-term time perspective. Moreover, more recent AE system developments in Sweden have been more limited to informal networks with a particular focus on promoting AE installations. One AE system inventor and entrepreneur of a new collector technology explained that experimenting and experience sharing (learning) was taking place through his personal business networks, e.g., university researcher, other entrepreneurs, building developers. (Personal communication, Entrepreneur and Innovator).

Box 1. Vässjebostäder, Swedish Aquathermal Energy Development

An example of household AE system development is located in the town of Hällevadsholm in the municipality of Munkedal. The multi-housing complex consists of three two-story buildings with 36 rental apartments. The complex was built in 1990; the AE system was installed at the same time. The system uses water from the adjacent small lake (Kolstorpevattnet), with a winter water temperature that never falls below 4 degrees C. The housing company does not own the lake so there is an easement with the municipality of Munkedal to use the lake.

Most of the AE system was exchanged in 2016 due to the age of the original system, while the collector was not updated. The present AE system is supplemented with direct electrical heating for peak demands for warm water and heating and cold days. The owner generally considers maintenance limited and costs for this low, which is likely related to the closed loop system characteristics. (Personal communication Board member Vässjebostäder).

Figure 9. *Dwellings where AE system is installed (right) and map of location of town of Hällevadsholm in southern half of Sweden. Source:Byggfakta (n.d.)*

Landscape level

Over the past 50 years there have been a variety of drivers that have influenced Swedish heating (and cooling) system development, and more specifically, the development of household AE systems. For this case, we concentrate on two significant parameters; each has had further direct implications for regime actors and actions (e.g., policies, technologies and market development, actor-networks). The two have both propelled and hindered AE system establishment. These are changes in the *geo-political* environment, significantly the oil crisis, and a stronger societal focus on *environmental issues*, including *climate change*.

Large geopolitical developments starting in the early-1970s have strongly influenced the Swedish heating and cooling landscape. It was during this period that a large portion of the Swedish heating, district and individual, was fuelled by oil and other fossil fuels. However, with the 1970s oil crisis, and steeply rising oil prices, there was a major push for change in the country with a focus on other feedstocks (e.g., biomass) as alternatives to fossil fuels. To mitigate the stressors on the energy system from the international oil crises, the Swedish government, in part, also intensified its efforts in the expansion of nuclear power and increased its investments in research and development (R&D) for alternative technologies based on domestic energy sources in order to reduce dependence on energy imports (Johansson 2021). This created a situation in the country where the share of oil halved between 1974 and 1984 (Wickman 1988).

In recent geopolitical contexts, many European countries face challenges as to how to ensure domestic energy security after cutting ties to Russian energy exports while simultaneously continuing transitions (Höysniemi 2022). Sweden is significantly less dependent on imported oil and gas from Russia than many other countries in Europe, and the energy supply in Sweden is generally robust. However, Sweden has been indirectly impacted by higher prices for energy carriers such as gas, coal, and oil (Swedish Energy Agency n.d.) where the increased electricity demand in other EU countries has created price spikes for electricity throughout the country, especially in relation to the Russian invasion of Ukraine.

In addition to the oil crisis of the 1970s, an increased focus on issues such as pollution in the country created a push for renewable energy system development. The prominence of climate change on the political radar in Sweden is most-relevant for the development of non-fossil fuel-based heating systems such as AE. Since the early 1990s, this has prompted a variety of regime level actions, a number of which are described below.

Socio-technical regime

Sweden has a number of regime level characteristics that make AE system development, of different sizes, feasible. In the following section we discuss key regime aspects creating both barriers and opportunities for AE development in Sweden.

Policies & Regulations

Based on the increased attention on environmental issues over the past several decades, policy developments have been given high priorities by the public sector at several levels. As an example, the high use of fuel oil in boilers resulted in high emissions of sulphur dioxide in Swedish cities and towns. It was concluded that cities and towns with district heating systems had lower air concentrations of sulphur dioxide (Werner 2017) since single sources with higher chimneys created local concentrations. Based on efforts to reduce these emissions, a national tax for sulphur content in fuels was later introduced in 1991 (Swedish Parliament 1990).

High air nitrogen dioxide levels from the combustion of fossil fuels also prompted policy changes in Sweden (Werner 2017). To quell the emissions, a trading system was introduced in 1992 (Swedish Parliament 1990) creating fees on nitrogen dioxide releases. Since 1990, the introduction of the system has encouraged various technologies for reduction of nitrogen emissions by 65% (Swedish Environmental Protection Agency 2006).

An awareness of climate change in the 1980s also created a policy focus to reduce carbon dioxide emissions in the energy sector. Since a general European carbon dioxide tax scheme in the late 1980s never realised, the Swedish Parliament instead took the inspiration from the initative and introduced a national carbon dioxide tax in 1991 (Swedish Parliament 1990). The initial tax was approximately €25/ton, and has since progressively increased to the level of €110/ton by 2016. As this tax level was considerably higher than the price level of emission rights within the

European emission trading schemes, fossil fuels were heavily punished in Sweden (Werner 2017). In addition to steady changes in household heating systems throughout the country, the carbon tax has also stimulated the growth of centralised district heating systems that are increasingly fuelled by sources such as household waste and wood residues, household wood pellet systems, and heat pump systems.

For Sweden the results have been the progressive phasing out of fossil fuel-based heating in the country, dropping by more than 90%, and accounting for a very small share of the country's total greenhouse gas emissions (Ministry of Infrastructure 2021). The migration to non-fossil fuel sources have not been without their contestation, however. Bioenergy (e.g., forest products) and the burning of municipal household waste have sparked political debates, especially in recent years and in the context of EU forest policy. As one example the EU proposal for a new Renewable Energy Directive (RED III) has been considered a risk by the industry hindering the continued use of bioenergy, but where the final agreement emphasised, among others, cascading principles in a way making continued use of biomass more favourable (e.g., Swedish forest industries 2023).

Recently, some new state level policy initiatives were launched, especially since the start of the Russo-Ukrainian war, to improve household energy efficiency and to stimulate the warming of dwellings by electricity or natural gas combustion. An example that has been available since mid-2023 are grants for home-owners to support material costs to move household heating systems away from direct-warmed electricity systems or natural gas-fired systems (SFS 2023:402).

Regarding permitting for installing the single housing closed loop AE systems, regional and local governments in Sweden have established permitting and easement systems (when the collector or connector pipes are placed on land with a different owner) in place for the installation of AE systems although they do differ between different government bodies (Personal Communication Entrepreneur and Innovator; Personal communication HVAC Company). However, most processes are straightforward. Specific factors that can influence the permitting process include the lake's energy capacity, bathymetry, requirements on materials and installation processes and signage. Municipalities normally handle permitting requests within a few weeks time. In more complex instances such as if an installation is impacting or occurring in a water protection area or in other protected areas (e.g., National parks, Nature 2000, etc.), or is being appealed, the permitting is normally handled by the county administrative board. In addition, other risks such as boat anchoring, storms and ice movements at the shoreline need to be considered in the physical installation.

Technologies & Markets

A variety of "clean" commercially-available household heat pump technologies have been available in Sweden for several decades. This includes bio-based systems such as pellets- or wood-fired systems, air source pumps, deep and shallow geo-thermal (ground and rock) pumps, and AE systems (Swedish Energy Agency n.d.). These systems have improved in quality and efficiency over the years (Johansson 2021). Furthermore, and as mentioned, a large share of buildings, especially multi-family dwellings have access to centralised district heating in most larger urban areas.

The price of the different technologies along with the region in which the dwelling is located, and (if relevant) the existing household heating system have important implications on the system chosen. Air exchanger (air to air) systems are relatively inexpensive and can easily augment or replace existing systems, especially those without an existing thermal radiator system throughout the dwelling. Wood-fired systems have higher installation costs; however, they can rather easily replace existing oil, natural gas or electric systems. Geothermal systems have greater establishment costs, but low operation costs. These systems are generally connected to new or existing thermal radiators to provide the heat throughout the dwelling.

Over the past decades, the Swedish AE regime has stimulated several enablers (e.g., networks, policies, technologies) to stimulate a technological take-off of domestic heat pump systems, to some degree also AE system development, throughout the country. Market actors promote the systems as efficient, a good economic investment, environmentally-friendly, low maintenance, and flexible to combine with other heating or cooling solutions (Värmepump.se n.d.).

However, regime level hindrances have also inhibited AE to reach its potential as commonly-used heating (and cooling) technology among Swedish households. AE's competition with other heating technologies impedes the technology from wider distribution in dwellings in Sweden. First, AE must be situated in the vicinity of a water source (e.g., a lake, river, or the sea). Despite Sweden having a long coastline, many lakes and rivers, not all homes are located sufficiently close to such water bodies and also may include easement. For the larger rivers in the northern parts of the country some barriers consist of cold water in combination with high turbulence. For homeowners interested in heat pump system technologies, this often makes geo-thermal system installations a more feasible option, where a collection hose can be strung out on the property or a vertical hole can be drilled for the thermal extraction.

Competition with DH in Sweden is another inhibiting factor for AE system development. As stated, most urban areas in Sweden have existing district heating networks, which makes the appeal of installing other heating and cooling systems uninteresting to homeowners. With this stated, however, there has been some backlash against DH suppliers recently due to increasing prices for the DH and their monopolistic standing as the heat supplier for each DH system.

Overall, there are a number of actor constellations in Sweden that have contributed to larger level heating system development. (Renewable) energy communities are a form of actor arrangements that can drive system developments. Nordic countries have a long tradition of development and previous dominance of municipality-owned energy systems such as DH. viewing community energy in a more conventional way Sweden, in 2019 had 140 energy community initiatives active. However, only ten of the initiatives were small-level heating organisations, making the use of energy communities as a development vehicle in Sweden relatively weak (Magnusson and Palm 2019).

3.2. Case study 2: The Governance of AE System Development in the Fryslân Region, The Netherlands

3.2.1. Background

In the Netherlands, natural gas is the largest source of domestic energy production and a key fuel for industry and for building heating. The gas field in the north-east part of the country in Groningen is one of the largest gas fields in the world and was historically the main source of domestic gas production. Due to land instability and earthquakes caused by gas extraction in the Northeast Groningen area, there has been large-scale damage to property, which has led to concerns by the public and various calls to stop gas production in this area. This, together with less dependence on Russian gas supplies, has led the Netherlands to intensify its search for sustainable energy solutions, even pursuing a heat transition since 2018. This includes the willingness to phase out natural gas and encourage the use of renewable sources for heating purposes. Among the renewable sources available there is attention to aquathermal resources, hence the willingness to explore AE possibilities.

An important initiative that results from this is the ‘Green Deal Aquathermie’ which refers to an agreement between twenty actors in the energy and water sectors, referred to as ‘parties’, that have an interest in AE solutions for the Netherlands. The deal was signed in 2019 with the objective of collaboration between parties to work together to improve the value and application of AE as a heat and cold source in the Netherlands, with which they aimed to accelerate the heat transition. The parties that are part of this agreement include several government departments including national, provincial and local levels, the Union of Water Boards (federation of water boards in the country), the Association of Water Companies, research and academic institutes.

As part of working on the Regional Energy Strategies (RES) in thirty energy regions in the Netherlands, to lower carbon emissions and contribute to achieving the objectives from the national Climate Agreement (the main governance arrangement to combating climate change in the country), the Netherlands is in constant search for sustainable energy solutions. In the ‘Green Deal Aquathermie’, actors agree to work together to improve the value and application of water as a source to heat and cold. This is seen as a way to assist finding sustainable ways to accelerate the heat transition.

The parties also committed to communication and information sharing about the value of AE as a heat source and cold source with all opportunities, risks and dependencies, building on the research and inventories that are already there. This information can be used by water managers involved in permitting (water quality, water safety), by authorities in RES and by municipalities when drawing up the local heat transition vision (TVH). The parties are also committed to have a joint knowledge and innovation agenda to identify steps that need to be taken to stimulate broad, large-scale application to make aquathermal energy possible. Issues of governance also take priority in ensuring that the policy making process keeps up with development and scaling of AE innovation. Stakeholders - including the Ministry of Economic Affairs and Climate - have made a commitment to make effort to address restrictive legislation and regulations for aquathermal energy where necessary and possible.

The Green Deal gave rise to the so-called ‘Netwerk Aquathermie’ (Aquathermal Network; an innovation network in Dutch, translated by the authors), an innovation oriented actor network, which ensured an increased awareness of aquathermal energy in the country amongst various stakeholders. The network also established that this renewable source for heating and cooling is already used in numerous (new construction) projects. Also due to the efforts of the Aquathermal Network, it has been included in the current coalition agreement of the national government as one of the important sustainable heat sources for the future. The ambition for the network is to heat and cool more than 200,000 housing units with AE by 2030 (Benning, 2023).

With regards to governance considerations in implementation of AE systems for large scale low-carbon energy supply, the Aquathermal Network documented identified needs required for governance processes (Benning, 2023). This included listing the necessary stakeholders key to achieving the implementation of large scale AE projects. The key stakeholders included, but were not limited to: water source holders such as water boards and similar authorities; energy supply network operator; energy or heating companies; funders and key investors; building owners like housing associations; building contractors, local level government / municipality; and provincial government. The variety of stakeholders make it clear that the implementation of large scale AE systems is not possible without establishing public-private partnerships. Van de Witte (2023) studied the implementation of AE projects in the Fryslân province and similarly concluded that for sustainable implementation of such projects, particularly large scale projects, having public-private partnerships is considered a necessity. According to research conducted by STOWA (2023), the governance of implementation of AE systems should focus on three key areas, namely: the ambition of the organisations involved; the organisation's role and culture, and policy that will provide direction to the project implementation.

Recently, several municipalities in the Netherlands have shown an interest in AE as an alternative energy source that could assist in reducing dependence on fossil fuels and cutting carbon emissions (Benning, 2023; Goossens et al. 2021). A feasibility study conducted in the Utrecht Heuvelrug area investigated several factors that would need to be fulfilled for implementation of such AE projects since the Utrecht provincial government has shown an interest in future AE implementation. Goosens et al. (2021) assessed the importance of location, the level of interest in AE among stakeholders in this area, the policies already in place for such project implementation and the barriers that could hinder adoption of this innovation. Results from this study showed that attention should be paid to technical and governance criteria. It also showed that it would be difficult to implement AE systems in the specific geophysical context for household cooling and heating due to the long distance between the suitable water sources and the residential area where the energy would be used. The homes were also not sufficiently thermally insulated, too much dispersed from each other, and located at a higher elevation than the water source, which was considered problematic (Goosens et al., 2021). Lack of knowledge among the community and low possibility of communication opportunities about AE systems was also considered a barrier to potential implementation. As per the respondents interviewed, Goosens et al. (2021) found that collaboration was considered of key importance to ensure success of such a project. Getting different stakeholders involved is key in ensuring a balanced AE project that would be sustainable in terms of operations and fulfilling the energy supply goals. Similar to Van de Witte (2023), Benning (2023) and the Aquathermal Green Deal, this study found that it is essential to get stakeholders involved in (experimental) projects (hence, implementation processes) such as the municipalities, water boards, renewable energy cooperatives (if they exist in the area), the provincial government, and the heating company. Most important above is getting commitment from funders, to have an agreement between homeowners and social housing associations for successful implementation of AE projects (Goosens et al., 2021; Van de Witte, 2023 and Benning, 2023).

3.2.2. Context: regional setting

The Province of Fryslân has shown high interest in AE and is also part of the Aquathermal Network. At the provincial level there is an established working group that consists of the Province, Water Board and four municipalities (Van de Witte, 2023). The working group has created a mission called 'Wetterwaarmte' ('water warmth' or 'water heat' in English, translation by the authors) which highlights that its mission is to develop and share information and knowledge, execute projects and formulate projects. Due to its abundance of surface water - with many lakes - in the province, it is believed by the provincial government that once the development phase of aquathermal projects has been realised, up to 60% of energy needed for non-industrial purposes will be sourced from AE operated systems (Fryslân, 2023).

According to the information dissemination material compiled by the Province of Fryslân, there is currently a degree of high dependence on natural gas for cooking and heating. There needs to be a 50% reduction in fossil fuel emissions by the year 2030 and 95% by 2050 (Fryslân, 2023). There are several local initiatives having ambitions of using AE for heating individual homes and buildings. To support this - and part of an implementation process - there are several partners that work together, including the provincial government, municipalities, renewable energy cooperatives, and heating companies. The local initiatives include projects in the village of Heeg where water from the Heegermeer lake is used to generate energy for space heating; in the village of Oudehorne water from the river Tsjonger is used to generate heat since 2018 and in Leeuwarden a province-owned environmentally friendly building - 'It Swettehûs' - was constructed, fully heated with AE (Fryslân, 2023). The provincial government has plans for large scale aquathermal projects with the aim of heating complete neighbourhoods, hamlets and villages. Relevant ongoing projects in the province are found in the cities of Heeg, Sneek, Leeuwarden, Balk and Terschelling (the latter pertains to a municipality on an island in the Wadden Sea).

Figure 10: *Map of Wetterwarmte AE pilots in Fryslân . From: https://www.fryslan.frl/wetterwaarmte*

3.2.3. Contextual Interaction Theory (CIT) Analysis

To analyse how policy supporting adoption of AE systems is implemented in the case study CIT is used. CIT analyses the implementation process through the interaction of actor characteristics, in particular, their motivation, interaction and power' (Bressers 2004). These actor characteristics are key in revealing what influences the interaction process or the direction of an implementation process in any context. The framework takes into consideration the specific, structural and wider contexts. The specific context is concerned with specific case or project circumstances and their influence on the interaction or implementation process. The structural context considers the influence of governance, including institutions, actor networks, policy mixes and instruments. The wider context is concerned with global political, economic and cultural factors influencing the interaction and implementation processes (Bressers 2004, 2009).

It is important to ascertain who are the key actors in the implementation of AE systems in The Netherlands. In the broader context, there are several actors that can be part of AE projects. The Aquathermal Green Deal document provides a clear indication of the actors with an interest in implementation of AE systems in the Netherlands and ensuring that this energy technology has a role in the energy transition process of the country. There are twenty actors who committed themselves to working together to find ways to find solutions and implement AE technology as widely as possible (Aquathermie Green Deal, 2019). The actors include central government, provincial government, local government (municipalities), water boards, the federation of water companies, academia, private companies, as well as energy and water research institutes. Among the list of actors, it is noted that there is no representation of renewable energy cooperatives or social housing associations, even though these stakeholders are mentioned as having a key role in successful implementation of large-scale AE systems (Benning, 2023; van de Witte, 2023). In fact, there is no representation of consumers or potential end-users at the household level or from industry.

For the Netherlands case, we see the involvement of housing cooperatives and energy cooperatives in specific cases such as in Fryslân . In Fryslân there are several initiatives using aquathermal energy for heating individual homes and buildings. As part of this implementation, there are several partners that work together, including the provincial government, municipalities, energy cooperatives and heating companies. As part of its mission to explore AE options, develop ideas and plan for implementation of this innovation, the province has established the 'Wetterwaarmte' working group where it collaborates with other stakeholders from the Water Board and municipalities.

Motivation

Each of the different actors have their own motivations in taking part in the AE systems project process. The government actors have a specific motivation to seek sustainable energy solutions, lower carbon emissions and achieve the measures set out on the Climate Agreements that they are part of (Benning, 2023; Goossens et al. 2021).

Sources of motivation as defined in the CIT include one's own motivation, external pressure and self-effectiveness assessment. At all three government levels the actors are highly motivated by their context as well as external pressure. Their own motivation is influenced by their role in contributing to the Regional Energy Strategies (RES) whereby suitable and sustainable energy options are considered for implementation throughout thirty energy regions in the Netherlands. This motivation is closely connected to the external pressure motivation based on the national Climate Agreement and global efforts to transition and decarbonise energy systems.

The Province of Fryslân is an actor that is also highly motivated for positive implementation of AE projects in the region. Its motivation is based on their specific context as they are currently highly dependent on natural gas for cooking and heating. With a motivation of wanting to have 50% reduction of fossil fuel emissions by 2030 and 95% reduction by 2050, the Province of Fryslân is open to new energy technology innovations that can help them to achieve these goals.

Actors such as energy technology development and suppliers also have their own motivations which include the provision of sustainable and climate friendly energy solutions.

Local actors such as renewable energy cooperatives are also motivated to have AE systems as part of the energy sources to empower local communities, but this motivation is limited to some extent by lack of knowledge and information about these systems and the regulations that govern them (van de Witte, 2023; Goosens et al. 2021). The buy-in from communities in the form of individual households, renewable energy cooperatives and social housing associations is important for successful implementation of AE. For these actors, the costs of installation may hinder their motivation, especially in old buildings that may need to be renovated and insulated for efficient AE heating and cooling. This could be overcome by the public government providing financial-economic incentives like energy subsidies or supportive tax measures for households, particularly those that cannot afford adopting AE technology otherwise.

Cognition

In CIT, cognition refers to information processing capacity held by an actor and how this contributes to the interaction process. The way the actors interpret reality, information and knowledge about each other and the context they are operating in, influences the interaction and implementation process. In the case of actors that are part of the Green Deal Aquathermie, it is clearly stated that one of the objectives of working together is to have the ability to generate and exchange information and knowledge. This information and knowledge is important to explore possibilities of implementing AE systems in the Netherlands, as well as to assess risks and dependencies associated with this technology and to find out how different actors can contribute to this, based on the information and expertise they have. This in turn, will assist in finding sustainable ways to accelerate the heat transition.

Lack of information can also negatively influence the implementation process of AE systems. As mentioned above and as pointed out in studies by Witte (2023) and Goosens et al. (2021), even though there is some interest in AE innovation, lack of knowledge and information may deter the motivation to implement such technologies.

Resources and Power

Different actors try to exert influence to decision making based on their expertise and resources. In the case of the Netherlands, the parties that are part of the Green Deal Aquathermie have resources that would enable them to be part of those that influence the implementation process. Government actors like national government, provincial government and Water Boards use resources they have like authority to influence policy, financing and regulation of AE systems. The Province of Fryslân has used its (financial and human) resources and authority to establish a working group to focus on AE innovations for the province. To demonstrate how well AE can work, the provincial government had the "It Swettehûs" building constructed, deeming it, “a new support point for the Provincial Water Management and a new centre for the operation of forty bridges” (Province of Fryslân, 2023). This building is fully heated with AE and operates energy-neutral.

Lack of resources can also influence the actor’s levels of participation in decision-making and use of AE systems.

Specific context

The specific context of Fryslân makes it attractive to consider AE as an option for energy generation. The provincial government has an abundance of surface water which is said to have the potential to produce 60% of energy needs for non-industrial purposes once large scale AE systems have been developed. There are also municipalities that are willing to work with the provincial government and the Water Boards to realise the potential of AE use. The presence and involvement of social housing associations and renewable energy cooperatives that are keen to take part in this implementation is also an advantage for the provincial government. Having local actors that are familiar with the context such as the energy needs and availability of resources is key for the Province of Fryslân.

Structural context

The structural context in the analysis of the Netherlands' process of implementing AE, clearly shows that establishing partnerships is essential. The variety of needed stakeholders make it clear that the implementation of large-scale AE systems is not possible without a public-private partnership (Benning, 2023; van de Witte, 2023). The networks that work together on AE innovation development and implementation can influence the 'take-up' and drive investments towards this technology. The step taken by stakeholders in forming the 'Netwerk Aquathermie' exemplifies how different actors can and should work together towards the implementation of AE. It shows that in order for an innovation to be accepted, there needs to be a buy-in from actors that can envision the benefits of such an innovation. Another structural context factor is multi-level governance and the role the European Union has. Local projects in Fryslân benefit from EU Directives like REDII that (after transposition in national legislation) enable local stakeholders to adopt AE and related technology.

Wider context

In case of influence by the wider context, the key motivations for AE implementation in the Netherlands is to produce sustainable energy, meeting climate goals and to lower the dependence on fossil fuels such as oil and gas. The geo-political climate also plays a role in the need to reduce costs of energy, therefore searching for local and sustainable solutions. Over the last three years AE developers benefitted from a political culture in favour of low carbon innovations supporting sustainable energy transitions. However, more recently this has become the subject of attention from far-right political groups who are not happy with it. More recently in November 2023, a far-right party won the national elections, a party that "wants to put climate policy through the shredder". If this party takes the lead in a right-wing government coalition, this could be detrimental to policy aimed at supporting AE.

3.2.4. Reflecting on the Fryslân case using other theoretical frameworks: MLP, SNM, GA, GoC, CE

Next to analysing the Fryslân case using CIT is also useful to have an analytical look at the case using a MLP, SNM, Governance Arrangements (GA), Governance of Change (GoC), and a community energy (CE) analytical lens.
When using **MLP** the following is noticed. It particularly highlights landscape events influencing AE niche development in a positive way, while socio technical regime factors are highlighted impeding it. At the landscape level three major events are discerned that can have an important positive influence on AE innovation and diffusion. First, attention to climate change has risen over recent years and is impacting national and regional efforts to encourage the adoption of renewable energy like AE. Especially COP21 (Paris Agreement) spurred attention among policy makers, and encouraged adoption of ambitious climate goals by nation states like. For example, The Netherlands implemented these and formulated the national Climate Agreement (a meta governance structure) raising attention to and stimulating adoption of renewable energy technology. Second, earthquakes caused by gas extraction in the Northeast Groningen (not far away from the Fryslân province) in 2018 led the Dutch national government to start a heat transition to let go off natural gas, and look for renewable heating sources instead. This fuelled nationwide attention, agenda-setting for sustainable heat transition, which also led policy makers to develop several programs beneficial to local experimentation with renewable heat sources and overall stimulation of heat pump technology adoption. Even legislation was implemented mandating that gas boilers be replaced by hybrid heat pumps as per 2026. Third, the Russian invasion in the Ukraine spurred surging gas prices, which made using renewable heat sources comparatively more competitive to end consumers, in particular steeply rising market demand for heat pumps and thermal insulation. Regarding the sociotechnical regime the case revealed the presence of restrictive legislation and regulations that cause hindrance when permits are required to apply AE.

Using **SNM** mostly addresses attention to how innovation occurs at the niche level. This mostly addresses the three key tenets to niche innovation in terms of: (1) network formation, (2) setting visions and expectations, and (3) fostering learning from experimentation. Regarding the Fryslân case and the attention to AE in the Netherlands the following can be observed. With regard to network formation the ‘Green Deal Aquathermie’ can be viewed as a key document that sets the basis for actor collaboration with the aim to experiment with and scale AE technology. (Assumably) The Green Deal Aquathermie contributes to visioning and setting expectations about AE as a groundbreaking renewable heating technology.The document can be seen resulting from coordinated action of an actor network pursuing the objective of collaboration between parties to work together to improve the value and application of AE as a heat and cold source in the Netherlands, with which they aimed to accelerate the national heat transition. In this sense AE can be seen as contributing as a (sub) niche to the general heat transition. Moreover, at the regional level it contributes the latter whilst also fitting in with the regional energy strategy (RES) governance structure. Of key importance to AE niche development is the ‘Netwerk Aquathermie’ which serves as an actor-network coordinating AE innovation activities between different local and regional experimental projects. This can also be said about the role the province of Fryslân has a key intermediary advocating AE interests, whilst encouraging experimentation and scaling of AE. In addition it is also active in setting first mover demonstrations like the ‘It Swettehûs’ building, whilst encouraging reflective learning within and between local AE initiatives. With regard to learning and experimentation the parties who are signatories to the ‘Green Deal Aquathermie’ are committed to communication and information sharing. This information can be used by water managers involved in permitting (water quality, water safety), by regional authorities in energy regions (informing RES making) and by municipalities when drawing up the local heat transition vision (TVH). The parties are also committed to contribute to a joint knowledge and innovation agenda to identify steps that need to be taken to stimulate broad, large-scale application to make aquathermal energy possible. At the provincial level the same can probably be said for the role the Province of Fryslân in facilitating knowledge development in AE experimentation.

Issues relevant to a **Governance Arrangements**’ focus on AE niche development in the Netherlands pertain to ensuring that the policy making process keeps up with development and scaling of AE innovation. The nature of implementation issues surrounding AE make it clear that intersectoral collaboration is desirable. This calls both for active involvement and interaction between private and public sector actors. Implementation of large scale AE systems is considered not possible without establishing public-private partnerships. Moreover, cross-sectionality also calls for addressing how policy workers from different sectoral silos (e.g., water, energy, spatial affairs) can collaborate to make sense of the institutional complexity of AE projects and develop practical solutions. Finally, we observe that existing governance arrangements and policy mixes pertaining to the national heat transition are beneficial to AE niche development in regions like Fryslân. For example, there are three local AE projects partly funded by the national heat transition experimentation program ‘Aardgasvrije wijken’ (‘PAW’; natural gas-free neighbourhood in English; translation by the authors). Moreover, subsidies and regulation stemming from the national programs stimulating heat pump take-up and thermal insulation also benefit AE adoption.

Finally, attention can be paid to the role and involvement of **energy communities** in the Fryslân case. Current projects involve renewable energy cooperatives (REScoops) who initiate, plan and co-develop local AE projects. Although they are relatively small-sized organisations, often lacking organisational maturity and professionalism, REScoops are key actors in Frisian AE niche development. The CE literature can be used to analyse their role in setting up sustainable heat projects, how they reach out to and mobilise legitimacy among local communities, analyse under which conditions they can fare successfully, and address how they can be supported in co-developing and running their projects. Regarding the former, mobilising legitimacy can be considered an important tenet contributing to **Governance of Change**. The same can be said for deploying the right mix of public policy and non-state agent instrumentation (see for the latter again the example of energy communities using their agency to mobilise social legitimacy among local community members).

A GREEN TRANSITION

Chapter 4. Synthesis

4.1. Main takeaways from the two case studies

The main takeaways from the Swedish case study of household AE development are that proactive efforts, especially policies, spawned non-fossil fuel based household heating technology development. This supported technological developments of AE systems. However, competition with other similar heating (and cooling) systems such as shallow geothermal and air-air systems has also hindered a broader takeoff for AE systems throughout the country. The significant factors that have supported or hindered Swedish household AE development are highlighted in Table 3.

Table 3. *Summary of main enabling and inhibiting factors of the Swedish household AE system development case.*

Landscape event	Regime factor	Regime aspect	Enabling or Inhibiting?
Oil crisis (early 1970s)	Policies		Enabling
	Technology & market development		
Environment and climate focus	Policies	Carbon tax/trading scheme	Enabling
	Policies	Nitrogen & Sulphur taxes	Enabling
	Technology & market development	Technology development in AE systems	Enabling
	Technology & market development	Better geothermal heating and DH technologies	Inhibiting (AE competition with other heating systems)
Geo-physical aspects	Technology	Close proximity to water sources (e.g., rivers, lakes)	Inhibiting
Administrative	Market development	Efficient local permitting processes	Enabling

Table 4 presents factors for the Fryslân case that either hinder or support AE development. The main takeaways from the case study are that high energy prices, (government commitment to) the Paris Agreement, its transposition in Dutch legislation and policy, as well as community energy initiatives present in the region to a large extent enabled the initiation of exploring AE technologies as an alternative to fossil fuels heating residential areas. Negative external effects of natural gas extraction and production in the Groningen region accelerated the development governance arrangements, issuing of policy and (national) programs encouraging adoption of sustainable heat options. This entailed national, provincial, regional as well as local level initiatives, jointly creating an enabling environment for AE experimentation, planning and project implementation. On the other hand, national government reimbursing households as compensation for surging gas prices following the Russian invasion in the Ukraine can be considered an impediment because this artificially reduces the price difference with the gas price, which removes the incentive for end users to invest in sustainable alternatives like AE. Another barrier observed pertained to restrictive legislation and regulations preventing and slowing down the granting of necessary permits in local AE project development.

Table 4: *Summary of main enablers and inhibiting factors of the Frisian AE system case in The Netherlands.*

Landscape event	**Regime factor**	**Regime aspect**	**Enabling or Inhibiting?**
Climate change – COP21 Paris Agreement 2015			Enabling – COP21 transposed in national Climate Agreement supporting adoption of renewable energy – also indirectly via the 'Green Deal Aquathermie' which was part of the Climate Agreement's 'Green Deals' package – and similarly via the Regional Energy Strategies (RES) empowering regional governance of energy transitions
Earthquakes in the Groningen region – since 1986 but a serious issue since 2012			Enabling – raised attention phase out natural gas use. Heat transition has been on the agenda since 2018 with enabling (national) programs on experimentation with neighbourhood approaches ('PAW'), heat pump adoption and thermal insulation adoption. Moreover, key to the heat transition policy is decentralised control via municipalities getting a coordination role, formulating TVHs (heat visions) and local heat tr. implementation plans
Culture of citizens wanting green energy systems themselves Energy cooperatives?			Enabling – Over years citizens have become more knowledgeable, aware and capable of mobilising resources to green (local) energy systems themselves. This is in part also a response to government and market failure to successfully encourage green energy transitions – momentum for the rise of community energy (per 2010)
Russian invasion in the Ukraine in 2022 – ongoing war			Enabling – surging gas prices are creating a window of opportunity for heat pump and thermal insulation adoption (which led to surging market demand and long waiting lists in supply).
	Partial reimbursement for surging gas prices (following Russian invasion)	(Sectoral) policy	Inhibiting – (partial) reimbursement works as a disincentive for households and other end users to invest in heat pumps and AE, because the price difference is made smaller
	Restrictive legislation	Sectoral policy	Inhibiting - restrictive legislation and regulations that cause hindrance when permits are required to apply AE. What makes things even more difficult is dependence on permit systems in different sectoral policy silos

4.2. Key takeaways from using the CIT and MLP frameworks

In this report, we have presented two country cases to exemplify how some of the theoretical frameworks we refer to can be applied to make sense of and analyse the different approaches that have been used to implement AE projects. Table 5 shows the key takeaways gathered from using the CIT and the MLP frameworks. We list the frameworks' elements and relate them to the factors that may and could influence the AE implementation processes in different contexts.

Table 5: *Key CIT and MLP takeaways*

#	CIT key takeaways	MLP key takeaways
1	Analyses the key actor characteristics that influence the interaction process	The MLP emphasises dynamic, co-evolutionary interactions between the niche, regime, and landscape levels. Changes in one level can influence and be influenced by changes in other levels.
2	The key motivations for the different actors include meeting national climate change obligations, lowering dependence on fossil fuels, innovation advancement in renewable energy production and ensuring access to clean energy for local communities.	Transitions are directly and indirectly influenced by factors in the broader landscape; these can include societal values, economic conditions, and policy changes. The external pressures create opportunities for niche innovations such as AE to gain traction or force change within the regime.
3	In terms of cognitions, information and knowledge generation about AE systems is important for all actors to enable suitable decision-making, influence policy decisions, and contribute to good governance.	Regime level actors respond to developments and changes at the landscape level. Regime actions can either impede niche level innovation developments such as AE systems, or support the innovations through the creation of new policies, markets, etc.
4	Resources and power are essential elements in the actor interaction and implementation of AE projects. Such projects are implementable only with the willingness of actors that have resources. In this regard, how each actor's power is perceived and used is also essential in implementing AE projects.	Transitions and the MLP allow practitioners to understand change processes over a longer-term perspective. Recognizing the historical development of regimes and understanding the trajectories of niche innovations allows for a deeper analysis of transition dynamics.
5	The specific context is important in assessing the feasibility of implementing AE projects. In this case, it is about assessing the appropriateness of the local conditions and how these match the needs for such implementation.	Managing transitions such as AE energy system development requires active intervention and governance. Policy measures, regulations, and supportive frameworks can facilitate the emergence and diffusion of these niche innovations.
6	The structural context provides a lens to assess the structures in place for implementation to take place. In the case of AE, stakeholder networks and multi-level governance systems are essential in the successful implementation of AE projects.	Formal and informal networks are key to driving niche innovation processes. AE system development will require robust constellations of actors including citizens, local government, interest organisations, and market players.
7	The wider context assesses the influence of geopolitics in the development and implementation of new innovations. The motivation to encourage AE innovations is partly based on the fragile global politics that have a strong influence on energy security, production and supply.	

Chapter 5. Conclusion

This report is part of the Interreg North Sea II WaterWarmth project which seeks to develop pilots and demonstrations that show the potential of AE with the particular aim that actors from the private, public and civic sectors adopt and implement joint strategies and action plans. Within this project this report results from work in Work Package 6 pertaining to Governance and Innovation of AE systems. The aim of this report is to present a literature study of relevant theoretical and analytical frameworks available to analyse the governance of current heating systems and future energy system innovation, in particular with regard to AE systems. After presenting a number of relevant theoretical frameworks the latter were applied to two empirical cases. One on household AE use in Sweden, and another on regional experimentation and scaling in the Fryslân case in the Netherlands. The research questions central to this report will be answered below:

Research question 1: How can we understand an AE transition in the EU in broader theoretical perspectives addressing sustainability transitions and governing change?

The report showed that AE projects and cases can be understood from different theoretical perspectives. Roughly speaking, they can be subdivided in three academic disciplinary approaches: (1) innovation and transition; (2) governance and policy; (3) community energy.

Research question 2: Which theoretical frameworks can be used to analyse transformative change and governance in practical AE cases?

For the innovation and transition discipline, two relevant theoretical frameworks were retrieved and considered useful: the multi-level perspective (MLP) and strategic niche management (SNM). For governance and policy, three theoretical perspectives were retrieved and considered useful: contextual interaction theory (CIT), governance of change (GoC) and governance arrangements (GA). For community energy, an overview of several theoretical and empirical approaches to community energy (CE) and community energy systems (CES) were presented.

Research question 3: In what ways can theoretical frameworks be used in practical cases?

The theoretical frameworks listed under answering research question 2 were used as analytical lenses when analysing two illustrative cases. The Swedish case showcased the relevance of MLP, presenting a longitudinal analysis highlighting several incumbent regime barriers impeding AE development and scaling. This served as explanation why AE in Sweden is currently a small niche market contributing little to transformative and environmental change of domestic heat systems. The Dutch regional case of Fryslân primarily served to showcase the use of CIT to highlight the importance of multi-actor agency influencing decision making in implementation processes of AE in regional cases. In doing so, it revealed the importance of several events in the specific, structural and wider context influencing AE implementation and diffusion in both positive and negative ways, indicating that actor interactions are highly subject to institutional rules and events that stem from national and international contexts, and cannot be influenced by local actor interactions alone. The influence of these structural and wider context events bear similarity with MLP's levels of the socio-technical regime and landscape. To explore further utilisation of theoretical frameworks, strategic niche management (SNM), governance arrangements (GA), and community energy (CE) were also applied to the Fryslân case. This exercise showcased additional (but sometimes also overlapping) insights) in the case. More importantly, it revealed the importance of theoretical complementarity in the case. For example, how governance arrangements and policy (mixes, instruments) support strategic niche management activities in national and regional AE innovation-diffusion coordination. And how international and national level governance arrangements and policy empower but also provide hindrance to regional AE strategies. Furthermore, it shows how specific actors like energy communities use their unique functional agency - i.e., in mobilising social legitimacy - to foster AE projects and experimentation.

Like all research this study is subject to limitations. First, the study only used two illustrative empirical cases, the one longitudinal focusing on household level adoption of AE in Sweden, the other cross-sectional adopting a regional approach in the Netherlands. In both cases EU countries in the North Sea region are addressed, presenting a potential bias to external validity, more particularly a 'eurocentric' bias. More in general, the Dutch case presents the narrative of a frontrunner country and region in AE adoption, downplaying the importance, complexity and difficulties later adopters may find when they engage in governing AE innovation and scaling quests. The two cases also served an illustrative purpose, with only little primary data involved. Future research should address this limitation in using more primary data. Next steps in the WaterWarmth WP6 research pertain to development of AE governance arrangements, in-depth empirical analysis of (additional) cases expanding to cities and regions beyond the countries presented in the present work, and co-design with stakeholders and policy makers of visions, pathways and policy mixes in selected practical cases.

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