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Fragmentation or integration? Exploring aquathermal energy governance

A Metropolitan Region of Amsterdam case study

Master's thesis – Master Spatial Planning

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Abstract

This research is a response to current literature that highlights the socio-technical complexities of metropolitan governance influencing the integration between water and energy infrastructures. It has explored institutional fragmentation in aquathermal energy application in the Metropolitan Region of Amsterdam, which is recognized as a leading European region in the energy transition. Document analysis and expert interviews have been used in combination with a theoretical framework that incorporates leading values, institutional settings, and spatial characteristics. This has shown how these external factors shape the coordination between relevant stakeholders in aquathermal energy use. The findings demonstrate the willingness for integration among sectors, which is hindered by the presence of unsuitable institutional frameworks that complicate the coordination on regional application of aquathermal energy. Therefore, they suggest the need for an overarching organ bringing together disciplines and spatialities, stronger municipal instruments, and more clarity and clear direction for involved stakeholders.

Keywords: *Water-energy nexus, metropolitan governance, institutional fragmentation, socio-technical transition, aquathermal energy.*

List of figures and tables

Table of Contents

1. Introduction

1.1. Problem statement

One of the most prominent challenges faced globally is the rising temperature caused by rapid human development and usage of the earths' fossil fuels in the Anthropocene. These developments have provided energy systems as vital infrastructures that have a large impact on the functioning and well-being of society, but currently operate using fossil fuels (Keirstead & Shah, 2013; Hoicka et al., 2021). With fossil fuel reserves depleting and disastrous effects experienced due to global warming, a transition towards sustainable energy sources is needed to keep vital infrastructures functioning and to limit fossil fuel emissions. To facilitate this transition, the Paris Climate Agreement was signed in 2015, which resulted in the Dutch Climate Agreement in 2019 (Janssen et al., 2020; Rijksoverheid 2019). One potential sustainable energy source that has received growing recognition within energy transition policies and circular economy ambitions over the past years, especially in the Netherlands, is heat from water, or aquathermal energy. However, exhausting the possibilities of using heat from water is not yet common practice. There is still much to be gained within this field, especially through the development of the water-energy nexus (Yumkella & Yillia, 2015).

This is also acknowledged by the national government of the Netherlands. In their recent plan for the national energy system (Nationaal plan energiesysteem), the substantial potential for sustainable, local heat sources has been recognized. These sources are of great importance for future energy demand since their utilization can limit the need for alternative heat sources, relieving the heating demand and the energy system (Rijksoverheid, 2023). Additional advantages would include a greater autonomy and more stable energy prices. Together with these advantages, the storage of sustainable, local heat sources can accommodate flexibility in energy supply within fluctuating situations of energy demand. In the report, aquathermal energy is specified as a local heat source with a high probable impact for supply to a collective heat network. Even though potentials coming with its application are highlighted in the national plan, it is recognized that, in order to achieve policy goals, governance and partnerships for collaborations still need to be shaped step by step (Rijksoverheid, 2023). This can be explained by the cross-sectoral interdependencies and socio-technical challenges that are involved in energy transition planning (Gürsan et al., 2023; Geels et al., 2017; Raven et al., 2012). Moreover, provinces and municipalities play a crucial role in the energy transition at the local and regional level, and for this reason the importance of connecting different scales and integral decision-making becomes clear. In fact, on these levels, clarity is needed in the short term if it comes to deciding where collective heat networks can be realized. This is needed to prevent individual heat solutions from overloading electricity networks, leaving the potential of collective networks in an area unuse

As the regional scale is an important implementation area where clarity is needed in the short term, this research will focus on aquathermal energy, or extracting heat from wastewater and surface water as local and sustainable heat sources (NAT, n.d.), within the case study of the Metropolitan Region of Amsterdam (MRA). By using underground heat storages, the heat can be stored to be used in winter for the heating of buildings through a heat pump, while the cold can be stored to be used for the cooling of buildings during summer. Heat pumps are essential to obtain desired water temperatures and thus for realizing this concept (Rijksoverheid, 2023). Heat pumps require electricity and, therefore, produce emissions to operate. Despite this fact, the initial temperature of stored water is relatively high and reaching the desired temperature for usage emits less compared to traditional gas heating systems (Hepbasli et al., 2014).

In addition to the functioning of aquathermal energy, the governance perspective for the application of such technology is of great importance for its realization, as is illustrated by the UNDP (2023): "*The selection of an energy source, its production and consumption, and the stakeholders involved all carry significant governance implications. (…) Such decisions are shaped by the governance structures in place, whether on a global, national, provincial, community or household scale.*". It is thus important to shape the governance in such a way that it makes energy governance systems more effective, inclusive, and accountable (UNDP, 2023). The report mentions the current energy crisis as an opportunity to accelerate the shift away from fossil energy sources, including the opportunity for a corresponding effective governance system. To succeed in this shift, it is crucial to have supportive frameworks and policies in place. Hence, active coordination among different government bodies is needed to ensure policy coherence. On the other hand, it should not underestimate the influence of non-state actors (UNDP, 2023; Bäckstrand, 2017). Having both state and non-state actors involved in different governance perspectives and in overlapping jurisdictions with a diversity of responsibilities, it is of great use to find out the challenges that these actors face in realizing a governance approach that facilitates the effective regional collaborations that are necessary (Raven et al., 2012; Hsu et al., 2020).

1.2. Knowledge gap

With the global need to abolish fossil fuels and to transition towards a sustainable and circular economy, aquathermal energy could be an important implementation to provide metropolitan regions with a significant part of their heat demand. The available technologies can, however, not be seen as the biggest implication of the nexus realization. Much more is needed, which brings us to the problem definition and research gap of this thesis, which finds itself in the governance perspective of metropolitan implementation and realization of the water-energy nexus, specifically aquathermal energy application.

Current literature on the topic of metropolitan governance tells us that, while governance structures are place-dependent, there can be found a common trend concerning the governance complexity and the issues that this brings along. The bottlenecks are often seen in the institutional settings and governance that are currently in place. There seems to be fragmentation in governance between sectors and across the jurisdictions within a metropolitan area, blurring the line of responsibilities and impeding the introduction of flexible infrastructures into metropolitan regions (Moss & Hüesker, 2019). Subsequently, ambitious policy plans in which metropolitan governments stress the transition towards sustainable energy sources are stagnating in the realization process, as institutional coordination does not concretely focus on (metropolitan) regions, but rather on policy implementation on provincial and municipal levels.

Metropolitan governance on nexus thinking is a relatively niche concept that still needs to be explored to fully understand successful planning. Debates on this topic (e.g. Covarrubias et al., 2019; Nicholls, 2005) argue that, for metropolitan projects, fragmentation and power distribution are factors influencing the success or rather conflicts within the governance arena: there would be a lack of, or gap in, coordination present. Consequently, metropolitan governance has the need to be restructured through the consideration of actors that had previously been overlooked (Nelles et al., 2018; Lefèvre, 1998). While these are suggestions to address metropolitan governance issues, the metropolitan scale is an overlooked topic in comparison to, for instance, the urban and local scales. No definite conclusions have been made regarding how this scale should be governed. Moss and Hüesker (2019) underline the importance of studying the understanding of fragmented, cross-sectoral metabolisms and encourages research *"to explore the socio-material dimensions to their relations across multiple scales and with the regions on which they depend to work the water-energy(-food) nexus"*. Furthermore, contemporary research is missing a concrete mapping on fragmented sustainability governance (Heidingsfelder & Beckmann, 2020).

This research focusses on the Metropolitan Region of Amsterdam as part of a collaborative project between Eindhoven University of Technology, Wageningen University & Research, and Utrecht University on the water-energy-food nexus for rural-urban circularity in the MRA (EWUU, 2023). In line with academic publications, the MRA faces similar challenges regarding nexus-governance (e.g. Heurkens & Dąbrowski, 2020; Geldermans et al., 2017). The organisation of the Metropolitan Region of Amsterdam refers to provincial research exploring what aquathermal energy could mean for the region, from which it is concluded that the largest part of the built environment in the MRA can be provided with aquathermal energy from surface water and wastewater (MRA, 2020). This is means that the potential for aquathermal energy use is also present in the MRA. Even though the potential and technology are there, application takes on a slow process and seems to be difficult to realize, which this research expects is due to institutional, sectoral, and jurisdictional fragmentation within nexus governance.

The research objective, therefore, is to explore the fragmented institutional arrangement in governing aquathermal energy use in the MRA and how this shapes the integration of water and energy infrastructure for the involved regional stakeholders. This brings us to the main research question that this research will attempt to answer:

"How can institutional fragmentation be addressed by stakeholders involved in aquathermal energy application in the Metropolitan Region of Amsterdam?"

To support the main research question, the following sub-questions have been formulated:

- *Who are the regional actors involved in aquathermal energy governance and what are their roles and responsibilities?*
- *How do the physical conditions, rules-in-use, and spatial context of aquathermal energy shape the integration between water and energy infrastructures?*
- *How do regional stakeholders involved in aquathermal energy application coordinate their activities within current institutional and spatial settings?*

1.3. Societal and scientific relevance

Policy documents and research on the MRA show that aquathermal energy is regarded as an important aspect in achieving circular and sustainability goals. However, implementation processes are facing governance challenges. This research aims to open relevant windows for the current governance landscape by addressing the institutional barriers for the application of aquathermal energy across the MRA. The aim for the insights is to be applied in future research in order to analyse different case studies with this research design as a basis, and further showcase the degree of the need for change in governance dynamics. By doing so, significant steps towards sustainability goals can be made, which stresses the societal relevance of this research. While scientific literature does discuss water-energy governance, water-energy and governance systems are place dependent (Berkouwer, 2021). This means that there is no framework in place to apply to any metropolitan region. This research adds to existing literature by producing output based on the MRA as a leading region in the energy transition, which insights other academics can use as baseline for the application to similar scenarios in different locations.

Now that the foundation for this thesis has been established, the following sections will first discuss the knowledge gaps through literature on the research topic. After that, the theoretical framework that is used for this research is discussed, and the methodological approach is described. This is followed by the results that were derived from the collected data, after which these will be given further meaning to in the discussion. Lastly, the research question will be answered in the conclusions.

2. Literature review

It is first important to gain a deeper understanding of the topics in existing literature that this research will use as its foundation. The following section will discuss both aquathermal energy potentials and why energy systems are in need for change and stressing their socio-technical character. After that, the governance debates on energy transitions and the energy-water nexus are discussed, after which this will be narrowed down to regional energy transition governance. These topics will be discussed to arrive at the research gaps that will be addressed.

2.1. Aquathermal energy potentials

Aquathermal energy is an aspect of growing importance in current day energy transition policies, for which the reduction of energy consumption and the transition towards a gas-free economy are predominantly argued to be of great essence in order to achieve policy goals (Rijkswaterstaat, 2020). The usage of aquathermal energy entails the extraction of thermal energy from water, which can then be used as a sustainable way to heat and cool down buildings (NAT, n.d.). Aquathermal energy can be extracted from three different (low temperature) sources, being surface water, drinking water, and wastewater. The extraction process involves a heat exchanger, via which the extracted heat from water is brought up to the desired temperature with a heat pump using electricity. This can go directly to the connected home(s) via heat infrastructures, but the extracted heat can also be stored in an aquifer thermal energy storage (NAT, n.d.). During colder months the stored heat from an aquifer thermal energy storage can be used, while houses can be cooled down during summer months with the cold that was stored during winter months.

The potentials of aquathermal energy are largely discussed in existing academic literature. Research by Schibuola and Scarpa (2016) has analysed the performance of a surface water heat pump as a renewable energy technology for the heating of buildings, compared to more traditional methods and in line with the European Union's Energy Performance Building Directive (EPBD). They discuss that this method brings multiple advantages, specifically as there is no surface area required and initial costs are low (Schibuola & Scarpa, 2016). The analysis underlines significant opportunities for the use of heat pump systems with water as a renewable source, also in historic city centres. Further potentials for heat extraction from surface water is discussed by Gaudard et al. (2019), where they explain that "the thermal use could significantly reduce the quantities of fossil fuels burnt for heating and of electricity used by air-based chillers for cooling." (Gaudard et al., 2019). They note, however, that the thermal use is only viable in proximity to its source, as efficient transportation of heat is difficult to achieve. Therefore, sources for thermal energy from surface water should be widely available in the implementation area.

Hubeck-Graudal et al. (2020) have explored the potentials of thermal energy from drinking water as a low-temperature heat source and conclude that thermal energy from drinking water should only be considered in areas where other energy sources are not available. Thermal energy from drinking water thus has a supplementary role within the energy supply. This is in line with the report by Unie van Waterschappen (2018), in which it is noted that thermal energy from drinking water can only provide around 1.4% of total heating demand (based on the Netherlands) and will thus play a limited role in the energy transition.

Nagpal et al. (2021) discuss heat recovery from wastewater, for which they mention that a significant share of energy consumption within households comes from the heating of water. The heated wastewater that leaves households is thus a valuable resource that would otherwise be left unused. Through extracting heat from wastewater, the recovered heat can subsequently be used for space heating in the building but will also provide a reduced energy demand, as the base temperature of water is higher and does not need to be heated to the same extend before usage (Nagpal et al., 2021). Moreover, Hepbasli et al. (2014) describe this potential by mentioning that wastewater flows are constant around the year, while close to 40% of total generated heat is left unused in most cities. They note that wastewater source heat pump technologies are available and proven to be more environmentally friendly than traditional heating systems like gas heaters. The main reason for this is the fact that heat pumps run on electricity and use this energy more efficiently than finite energy sources like gas. While it is a greener energy solution, it is still important to note that aquathermal energy extraction is not fully carbon neutral, as only part of electricity today is created through renewable energy sources (CBS, 2024). At the same time, this means that with the development of renewable electricity, aquathermal energy created through heat pumps still has the potential to become fully carbon neutral.

When discussing the energy that aquathermal systems need for the provision of heat, Gürsan et al. (2023) highlight the complementary function of electricity sources and heating systems in combination with aquathermal systems. Where the heating demand in winter is the highest but summer months provide an electricity surplus when using solar panels, this oversupply can be used to power aquathermal energy systems. To further utilize these circumstances, the produced heat can then be stored in thermal energy storages to be used during colder months (Gürsan et al., 2023). By complementing solar panel electricity and aquathermal energy systems, electricity surpluses are used rather than being sold back to the grid, resulting in lower energy prices, a partial self-sufficiency, and a reduction in carbon emissions. As aquathermal energy systems seem to be able to provide the same needs for society as gas-based systems, the authors argue that they have the potential to parasitize national gas functions (Gürsan et al., 2023). However, they also highlight the socio-technical grounds of such transition, where *"an emerging infrastructure system can (or cannot) replace an incumbent system on the condition that the previous urban and infrastructure co-evolution and the current socio-technical configuration allow this system change"* (Gürsan et al., 2023, p. 6). The implementation of aquathermal systems can face barriers rooted in socio-technical circumstances between policy and procedures. This is caused by, for instance, heat network ownerships, existing (long-term) contracts, and/or more attractive business cases, even though aquathermal systems can show the potential to help achieve policy goals (Osman, 2017).

Concludingly, this section has shown that aquathermal energy technologies show great potential in the transition towards gas-free cities, albeit place-dependent, especially in combination with other complementary green energy sources such as solar panels. It also displayed, however, that the potentials of alternative low-carbon heating systems being present does not necessarily mean that application can be realised effortlessly. The degree of implementation is connected to the socio-technical complexities that are currently in place and on which the energy transition is dependent. This results in the identification of a research gap, which translates into limited knowledge on the problems that aquathermal energy system implementation faces within current regimes. It becomes apparent that the governance arrangements in place do not effectively provide in the essential transition away from fossil energy sources. It highlighted the socio-technical interdependencies of infrastructure systems, which will be discussed in more detail in the following section to get a more complete understanding of the dynamics at work.

2.2. The need for change in energy systems

Before comprehensively discussing energy system transition governance that is needed for the implementation of aquathermal energy systems, it is important to define what energy systems are, why change is needed, the challenges that energy systems face together with their multidisciplinary complexity, and the effects this can project on policymaking. This can help us lay a foundation for the socio-technical debates that can be seen as one of the causes of implementation challenges.

Energy systems are vital infrastructures which dictate the inflow, outflow, and storage of energy within cities and city regions (Keirstead & Shah, 2013) and include the flows of fuel, heat, and electricity. While these infrastructures are mostly invisible to the end-consumers, they heavily influence modern-day life, economy, and the environment: without properly functioning energy system infrastructures, there would be restricted access to clean drinking water, heating and lighting for homes, and electricity to power computers on which businesses are run, to name a few examples. To maintain the proper functioning of energy systems, big changes are needed to accommodate for the growing energy demand and the decreasing availability of fossil resources (Hoicka et al., 2021). The question, however, is how this change should be implemented. Simply expanding the existing infrastructures and increasing their capacity based on the same fossil-energy powered technologies with which they were originally developed, is not sustainable in the long term. Not regarding fossil energy source reserves, nor the pressing issue of climate change that goes hand in hand with society's quality of life.

This brings us to another complication next to population growth, being climate change and the challenges that arise from climate change. Thus, energy systems should be developed in a sustainable way that supports population growth and is environmentally justified. Focussing on sustainable energy transition in cities is crucial, however, not straight-forward: a third complication for energy systems in cities lies with local scopes of action that often face difficulties. Policy goals are largely based on national data analyses, although it has become apparent that implementation on local levels (like city regions) are essential for energy system transitions. While local governments are creating their own climate policy plans, actionizing these plans is more nuanced as energy system government arrangements are often segregated. For instance, regulatory and financial influences are often situated in different levels of government (Keirstead & Schulz, 2010). These findings highlight the socio-technical complexities that energy systems involve. This complicates taking efficient action and is an indication of slow change in energy systems within current regimes, in a situation where the need for more radical change is widely recognized among governments. Aquathermal energy use is one measure for change away from fossil fuels. For its realization, water infrastructures need to integrate with infrastructures for energy supply, meaning that the success rates for aquathermal energy use are directly dependent on the degree of change in energy systems.

The section above has shown us what energy systems entail, as well as the importance that they hold in powering modern-day society. However, the current state of energy systems is being put under pressure due to rapid urbanization, climate change, and complex governance arrangements. The research gap following from this section is how a transition can be governed in the relative absence of regional-level specific policy implementation routes as policies are mostly based on national data, while regional policy implementation is crucial for achieving policy goals for the energy transition. As was discussed, this may be caused by the complexity of socio-technical arrangements around the transition of energy systems.

2.3. Energy infrastructure transitions as socio-technical change

The previous section has presented the importance of energy systems to society, contemporary developments that pressurise their sustainability and the consequential need for an energy transition towards carbon-free energy sources. This section will continue to discuss the energy transition. It will do so by defining the energy transition, while engaging with literature on the socio-technical character of energy system transitions and the debate on socio-technical transitions.

Before we can discuss energy transition characteristics and debates in more detail, it is important to establish the definition of an energy transition for this research. The sustainable energy transition is a topic that can be approached from a multitude of disciplines, which results it in having multiple definitions depending on the lens the energy transition is studied from. Smil (2017, p 9) has defined the energy transition as *"the change in the composition (structure) of primary energy supply, the gradual shift from a specific pattern of energy provision to a new state of an energy system"* with the lead motivation *"decarbonization, displacement of fossil fuel combustion by increasing reliance on carbon-free flows of renewable energy"* (Smil, 2017, p. 10). As this definition can be used to describe the shift away from fossil-fueled energy systems towards low-carbon and renewables-based energy systems, within which aquathermal energy systems fall, it is a relevant definition to be used in this thesis. While from this definition it becomes clear what the aim of the energy transition is, it can be argued that a lot is needed to realize this aim – in particular if this is to be done in line with the European Climate Law to be fully climate-neutral by 2050 (European Commission, 2021), or local initiatives that aim to be gas-free by 2040 (Gemeente Amsterdam, 2020). While these optimistic approaches may be stressing the necessity of transitioning, the past has shown that transitions typically span over multiple decades, if not a century (Solomon & Krishna, 2011). Furthermore, current energy usage still largely depends on fossil sources while the degree of dependence on a certain source is strongly correlated with the duration (and cost) of the transition into its replacement (Smil, 2017).

So far in this literature review, energy systems have mostly been described as physical infrastructures that provide different needs for society. It has become clear that there is a need for change towards low-carbon energy sources, and the potentials and availability of such sources, like aquathermal energy, are present. However, the transition of energy infrastructures does not solely rely on the available technologies and sources. Energy infrastructures are (embedded in) complex socio-technical systems. Gürsan et al. (2023) describe infrastructures as supplying essential services, such as energy, water and heating, being the foundation for the functioning of cities and the societies within. As societal needs should be met, the importance of properly functioning infrastructures is recognized and safeguarded through the development of policies by institutions, making infrastructures and institutions interdependent (Gürsan et al., 2023), which shape into a stable regime. A regime consists of multiple socio-technical dimensions, such as technology, policy, science, industry, market, and culture (Geels et al., 2017). For energy infrastructures to transition towards low-carbon energy sources, niche developments that can help to reach this goal are in need for support to integrate into a regime. Seen the multitude of socio-technical dimensions within infrastructure regimes, together with the stability that has been reached throughout its development, realizing change is a slow and complex task in which factors within a current regime can form barriers for radical changes (Gürsan, 2023). Still, it is these systems that are in need for change for the energy transition to be realized, and for that, the socio-technical character of infrastructure systems needs to be recognized and further understood.

Geels et al. (2017) recognize the interdependent socio-technical factors that influence energy transition processes. However, they argue that studies on the energy transition often fail to include the consideration of the multitude of actors involved in transition developments next to market driven transition developments, and show a limited understanding of transition processes, representing them as linear developments and implementations, while in reality this is more nuanced. Smith et al. (2005) had also recognized *"that firms and technologies are embedded within wider social and economic systems"* (Smith et al., 2005, p. 1) and the reason that transitions should be looked at through socio-technical regimes lies in the presence of overlapping market structures and the institutions and infrastructures that are already in place. A shift in focus away from market-driven sustainable developments and towards socio-technical regimes is needed, as this is where radical changes need to take place for the implementation of transition measures. Smith et al. (2005) articulate that the transition direction is defined by socio-technical regimes that are under continues selection pressure, in which the configuration of socio-technical regimes is built around stable infrastructures and institutional settings as a result from decades of development (Smith et al., 2005). They are developed by interdepended networks of public and private actors and institutions. These institutions have shaped the norms around infrastructures, according to which the involved actors behave. Implementing change within these settings is where the complexity of the energy transition becomes clearly visible. To describe a regime transition, the authors describe the adaptive capacity of a regime and describe the transition context (i.e. the direction of change in a regime) as the availability of resources and the way in which they are coordinated (Smith et al., 2005). While this is an insightful starting point, current research still struggles with shaping the integral processes that influence how transitions take place within regimes: Geels et al. (2017) emphasize that transition research often overlooks the socio-technical complexity of actors, institutions, infrastructures, and identified several problems regarding these approaches. This is being confirmed by Simoens et al. (2022), who argue that the reason for the limited understanding of barriers for radical change finds itself in the lack of research on the factors that provide stability or change in a regime. They follow the perspective that transition paths are institutionalized, *"meaning that its assumptions are unquestioned, and its structures are reflected in the material reality, institutional configuration, and social practices"* (Simoens et al., 2022, p. 1843), resulting in stabilized lock-ins.

Within lock-ins, debates on energy transitions between its actors involve multiple conflicts in values and interests and will present underlying political processes and frictions due to conflicting objectives and restrictions (Geels et al., 2017). Thus, the transition towards low-carbon energy sources involves complex socio-technical processes. While Geels (2002) had already argued the same regarding transitions in earlier academic work, this remains of importance for the transition of energy infrastructures today. Therefore, Geels et al. (2017) use a multi-level perspective to gain a socio-technical understanding of the energy transition and the different levels that it involves. Applying a multi-level perspective on transition for energy infrastructures can help in showing us the socio-technical processes that influence the development and implementation of transition measures (or niches) in the regime. Niche developments move through different phases before being widely implemented. In earlier stages, these developments are slowly gaining support but have difficulties breaking through in current regimes. They are obstructed by different socio-technical factors that are locked in place through their development over time (Geels et al., 2017). For instance, when the price and performance ratio of current energy infrastructures are more desirable, barriers can form against niche implementations. Furthermore, as long as supportive policies are in place for infrastructures within the regime, political and business barriers complicate the implementation of niches as there are no stimuli (such as subsidies) in place to develop next to or integrated with existing infrastructures. A ‘window of opportunity’ (Geels et al., 2017) is needed for niches to gain support from the socio-technical dimensions. Tensions in a regime can occur as a result of natural disasters or other frictions or changes that emphasize the need for radical change (Geels et al., 2017), after which changes in institutional coordination and infrastructures take place towards a new regime that include niche developments. However, more radical change is needed in the short term in order to achieve policies on climate change, and the question on how to achieve this is reflected in the debates on how to govern the energy transition within different socio-technical pathways (Lockwood & Devenish, 2024).

In conclusion, this section has shown us the socio-technical dimensions that influences energy infrastructure transitions as they are situated in a stable regime, together with examples of the ways in which they can form barriers for niche transition implementations. For niches to be implemented at the rate that is needed to mitigate climate change, radical change is needed within current regimes but is hard to achieve. Windows of opportunity can serve for broader niche implementation, but there is a need to further understand the socio-technical processes that influence the energy transition for effective governance. I will discuss the governance of energy transitions in more detail in the following section.

2.4. Governing energy transitions

In the previous section, I have discussed how socio-technical norms have been institutionalized within current regimes. The question on how to govern radical energy transitions implementations within regimes was raised. Therefore, the following chapter will discuss debates on the governance of energy transitions in the institutional socio-technical context. As this thesis focusses on aquathermal energy as a low-carbon energy transition measure, one section in this chapter will be dedicated to the governance of the water-energy nexus specifically, together with the spatial dimensions that are involved.

It is first important to state what this research understands by governance. Therefore, the following definition will be used to sharpen the focus of this section: "*governance can be defined as the interplay of actors and institutions as well as structures and processes"* (Benz and Dose, 2010, p. 27). Moreover, Lockwood and Devenish (2024) argue that institutions shape the 'rules of the game', and the results of certain governance structures depend on the institutional environment surrounding them. In this sense, this thesis will look at institutions as frameworks which decide the degree of change that may occur.

While different countries share the same goal of transitioning towards low-carbon source energy, the governance approaches to achieve this goal often take different shapes. These differences can be described as a result of the way in which the influence of governmental institutions on the provision of public services has developed over the years, thus how current regimes were shaped (Lockwood & Devenish, 2024). For instance, institutions in a state can be decentralized and give major responsibilities to municipalities for the local distribution of infrastructures. Relying on internal capacity can stimulate cooperation on local levels and more direct change through institutional intervention can be realized on the one hand. Friction between higher and lower institutional levels can occur on the other hand, as lower levels do not always have the capacity to accommodate the responsibilities that were given to them (Lockwood & Devenish, 2024). Others are liberalized and privatized, leaving little capacity of state action in service provision (Lockwood & Devenish, 2024). It can be said that this stimulates competition and development of niches in the energy transition, but at the same time a formal transition framework may not be in place, limiting the involvement of institutions in infrastructure developments (Lockwood & Devenish, 2024). This shows us that governance approaches largely depend on the historic development of the regime and, therefore, is place dependent. Moreover, its structure is shaped by the degree of institutional intervention.

Now that we have identified the importance of the institutional context for the governance of energy transitions, it is of essence to uncover the exact role that they play on different levels, and how this influences the interaction between institutions and other stakeholders involved in energy transition governance, as well as the coordination between the latter. Earlier we have established the interplay of socio-technical regimes, landscapes, and niches within the multi-level perspective. We add to our understanding of this interplay by incorporating spatial dimensions into this perspective, using the multi-scalar MLP (Raven et al., 2012). This perspective recognizes that the degree of change within socio-technical systems is defined by the developed regime, but, moreover, by the interplay of institutions and actors in different spatial dimensions (Raven et al., 2012). This approach underlines the interconnectedness of local, national, and international scales. This is of importance, as this research aims to touch upon the socio-technical debates revolving around energy transition governance which, based on the multi-level perspective, argue that *"there is a lack of geographical sensitivity in the MLP"* (Raven et al., 2012). One could find a difference in regimes on different spatial scales, as city regimes may be independent from (and at the same time embedded in and influenced by), for instance, national regimes. This was also raised by Bulkeley and Betsill (2005), who "*criticize the current environmental politics in literature for assuming global, national and local environmental politics are taking place in isolation of each other"* (Raven et al., 2012, p. 68). According to them, forms of 'new governance' (involving both state and non-state actors) should be recognized, which form networks within their institutional setting while at the same time sharing knowledge and values with actors across different spatial scales. This can influence the institutional governance of the involved actors, as the latter develop perspectives that are different from the context in which institutions enforce policies (Raven et al., 2012). Therefore, this clearly shows us that coordination between horizontal and vertical levels is complicated, as energy transition governance is influenced by the interplay between state and non-state actors on different spatial levels. This consideration of how change takes shape in socio-technical systems is important to understand for an effective governance.

2.4.1. Governing the energy-water nexus and nexus spatialities

Having insights into how socio-technical innovations can stimulate infrastructural change within the energy transition, how these processes are institutionalized and that this complicates effective governance, this next section will be used to take a closer look at the governance of nexus infrastructures within the energy transition.

In many past studies, researchers have tried to understand urban infrastructure dynamics mostly by looking at separate sectors, and while these studies provide useful insights into infrastructural changes within these sectors, Monstadt and Coutard (2019) argue, it is of great importance to consider cross-sectoral interdependencies for the understanding of urban dynamics. They note that while current infrastructure systems have traditionally been managed individually, water-energy and other infrastructures are complex and interconnected systems that should be governed as such (Monstadt & Coutard, 2019). However, currently it is observed that different sectors are not aligned in their development, which is exemplified by Moss and Hüesker (2019) with the wastewater sector trying to integrate into the energy sectors. Here, the water sector can face barriers that range from physical infrastructure conflicts to challenges in the spatialities of the energy market and the distribution of power among different actors. In terms of the governance of these critical infrastructures, the involved stakeholders recognize the essence of cross-sectoral collaboration but are situated in an 'institutional void' (Monstadt & Schmidt, 2019), where procedures and rules in policy domains and territories lack and *'they tend to focus on incremental amendments within their own jurisdiction and area of responsibility'* (Monstadt. & Coutard, 2019, p. 2198), due to which no effective collaboration is established. By using case studies from the global North and the global South, the authors demonstrate the strong political character of infrastructure integration. Confirmingly, Florentin (2019) notes that these political processes happen both horizontally and vertically, between and within involved organizations and governments. This shows us that, next to the argument of place-dependency in previous sections, there is a pattern of institutionalized complexity for infrastructure integration that manifests on multiple spatial scales.

Monstadt and Coutard (2019) further elaborate on the difficulty of infrastructure (co)development and territoriality across multiple scales for the governance of these essential systems. Where different sectors developed on different spatial scales, integration between domains *"invoke a new and complex spatiality of interconnectivities and interdependencies and blur the boundaries between different geo-political spaces that have barely been studied yet."* (Monstadt & Coutard, 2019, p. 2200-2201). For instance, where urban wastewater and regional energy systems aim for integration, new relations across scales can be found (Moss & Hüesker, 2019). While these can take positive forms like new business opportunities or inter-municipal collaborations, they can also uncover spatial mismatches (Moss & Hüesker, 2019) as infrastructures may be governed on different scales (e.g. local wastewater versus regional energy grids). This, in turn, raises questions for effective governance that needs to address fragmented institutions among different spatialities. Adding weight to these arguments, Raven et al. (2012) proposed a second generation MLP framework by adding a multi-scalar dimension to their analysis, recognizing the spatial sensitivity of socio-technical transitions. Socio-technical change, therefore, is determined by the linkages of actors between territories that have developed on different spatial scales (Raven et al., 2012). Finally, as we have now connected the socio-technical and multi-scalar characters of the energy transition, these factors are translated into governance by Di Felice et al. (2024). They emphasize the importance of nexus thinking, which EU policies are currently not sufficiently based on: policy models would exclude the relations between different elements and scales under the 'green growth umbrella' of, for instance, the European Green Deal. Therefore, transition governance should include nexus thinking – recognizing the relations between resources, socio-technical regimes, and spatial scales (Di Felice et al., 2024). The authors then call for the focus on local and regional governance, to bring change to current policy decisions.

This section discussed important literature on energy transition governance, highlighting the significance of institutions, actors, and spatial dimensions. Cross-sectoral challenges, especially in the energy-water nexus, hinder effective collaboration due to an institutional void. As a result, infrastructure integration across scales presents governance challenges, requiring acknowledgment of spatial complexities on which more knowledge is needed. It has connected the socio-technical and multi-scalar characters of the energy transition, in which governance should adopt nexus thinking. Yet, current policies often lack the focus on regional governance, which is why the next chapter will look deeper into this governance scale within the energy transition.

2.5. Regional energy governance

Considering the previously discussed literature, it is of the essence to include literature insights from energy governance on the regional level. By doing so, a deeper understanding can be gained on how the complexity of energy transition governance takes shape on the metropolitan scale that this research focusses on. It is first important to state that the terms metropolitan and regional governance are used interchangeably within academic literature (Macdonald, 2020), which also applies to the following section. A metropolitan area refers to a densely populated central urban area, encircled by various less densely populated regions such as towns, villages, and suburbs. While the exact geographical boundaries are usually determined based on population density and commuting behaviours, the defining characteristics of a metropolitan area lie in the strong and complex interdependencies of social, economic, environmental, and governance aspects between the local jurisdictions (Klink, 2008). The spatial connections that appeared put pressure on the existing governance structures, which are insufficient to address challenges arising within regions. With many local government bodies like municipalities that now have their jurisdictions within the region, metropolitan regions often face problems with the implementation and development of public services, and the coordination of policies (Slack, 2019). This is also true for the coordination of the energy transition, as the realization of this *"requires cutting across sectoral, scalar, and administrative boundaries"* (Heurkens & Dąbrowski, 2020, p. 19). Therefore, new governance arrangements are needed.

Hoppe an Miedema (2020) address what metropolitan governance of the energy transition is, and what it means in practice. Where earlier Laes et al. (2014) highlighted the challenging political circumstances for transition governance in general, this is confirmed regarding regional energy transition implementation by Hoppe and Miedema (2020, p. 24): *"governance is challenging, especially in the absence of a leading actor with a formal mandate to govern."*. This statement is based on circumstances regarding regional energy transition implementation initiatives, where progress stalled as regional priorities changed, and there was no established institutional framework for continuing implementations. However, newly entered energy actors, including a waterboard and an NGO, pushed to keep the initiative alive, albeit without a formal mandate, relying on voluntary efforts. This clearly showcases that, even when willingness is there, governance frameworks (or the lack thereof) can make regional energy transitions difficult to realise. Moreover, progress in the energy transition is limited because of dependency on national policy regulations and the regional agenda priorities: regional municipalities are seen as important actors for transition measures, while they may lack the capacity to coordinate energy transition governance, or it might simply not be prioritized in the region (Hoppe & Miedema, 2020). Moreover, a difference in willingness for collaboration between main cities in a metropolitan region versus its periphery can appear, causing uneven transition developments. This can be explained by Storper (2014), who argues that metropolitan governance undergoes influence from complex interdependencies within urban regions, combined with the disjointed geography and functions of the governing agencies. The presence of this fragmentation is not incidental but rather a response to inherent distinctions in district preferences, the optimal scale for the provision of public goods and regulatory measures, and the allocation of city characteristics across jurisdictions. Consequently, the progression of governance occurs in a seemingly arbitrary manner, characterized by incremental adjustments. Storper (2014) concludes by arguing that, even though modern (technological) developments can help in shaping metropolitan governance and its efficiency, metropolitan governance will always remain messy. Giving further perspective, Cox (2010) highlights metropolitan governance to be one of the problem areas within urban governance and argues that current literature is inadequate in addressing the fragmented nature of metropolitan areas. It would have a limited perspective in considering the institutional relationship between governance projects and broader fields of action. It is, therefore, of great importance to understand the structure of the state to understand the metropolitan governance and its challenges in a region. While Cox emphasizes that his findings (on the United States) are based on state structures that differ from Western Europe, Heurkens and Dąbrowski (2020) confirm them in their article on the energy transition as part of the development towards a circular economy in the Netherlands. The central challenge, they note, lies in how to achieve this transition within institutional frameworks that are based on a traditional, linear economy, as institutional barriers are found in current research regarding the governance of coordination between the high number of actors that are involved. Therefore, changes in present governance arrangements are required for circular developments to take place in cities (Fratini et al., 2019). It is said that present initiatives also fail to address factors like land use, geographical scales, and the complexity of urban systems (Williams, 2019).

Next to that, actors within regional scales are more and more connected due to the exchanges of economic and infrastructural activities which extend past the administrative limits of cities. Seen the missing focus on transition governance on the regional scale in current studies, Heurkens and Dąbrowski (2020) have investigated opportunities for shifts towards a circular economy on a metropolitan scale, while identifying transition barriers within implementations. By looking at different transition levels on which transition changes need to take place (strategic, tactical, reflexive, and operational), the authors argue that actions at one level impact governance processes at other levels, emphasizing the importance of interdependence in transition management. Therefore, it is crucial to gain a comprehensive understanding of the factors that facilitate or impede the energy transition.

These factors can, for instance, arise since policies and decisions are often (or at least in the Netherlands) being made on national, provincial, and municipal levels, resulting in the metropolitan scale being a grey operating area for all involved actors, without formal frameworks nor funds in place (Heurkens & Dąbrowski, 2020). As sufficient governance coordination lacks between actors that each have their own territorial responsibilities in a region, the energy transition towards a circular economy has a highly territorial character. This is why Walker (2022) stresses the importance to include the territorial perspective in regional energy transitions and argues that the urban and the rural cannot be seen separately. He explores the complexities surrounding energy transitions on regional scale and the dynamics of renewable energy adoption and its impact on urban and regional landscapes, shedding light on the challenges and opportunities in energy transitions. A central point in the article is the complex relationship between the distribution of renewable energy infrastructures and regional development patterns. For instance, it is argued how the strategic placement of energy transition measures significantly influences land-use decisions and economic activities within a region. Furthermore, Walker (2022) reveals how these infrastructure distributions can either boost or hinder regional development efforts. Strategic energy transition implementations can provide business opportunities and make a region more attractive, stimulating further development. At the same time, inadequate regional governance coordination can slow down regional developments, causing the region to miss out on policy achievement and economic advantages.

Additionally, complex land-use conflicts and governance dynamics that often accompany energy transitions are discussed, where conflicting interest between, for instance, agricultural stakeholders and renewable energy developers cause discussions over the allocation of land for energy transition projects (Walker, 2022). These findings highlight the importance of including a territorial perspective, so challenges and opportunities regarding regional energy transitions can be analysed and coordinated effectively. This once more highlights the socio-spatial character of energy transitions, where different structures and hierarchies are involved (or lack) within and between different territories, when energy governance overarches into different infrastructural domains and jurisdictions. This is supported by arguments made by van Dijk et al. (2022) in their research on the regional capacity to govern the energy transition (in a Dutch case study). As was mentioned before, the regional level is a grey area of operation (or 'no rules of game' are in place (van Dijk et al., 2022)) for the interdependent actors on this scale. Consequently, municipalities subdivide where specific energy transition measures will be implemented among themselves, an unorganized and messy process for multiple reasons. One reason here is the absence of hierarchical relationships, meaning that decisions cannot be overruled. They are instead based on imbalanced, individually strategic, discussions where some policy agents are less vocal than others, and in which an unwillingness towards making concessions can be identified (van Dijk et al., 2022). While some municipalities were reluctant to take on commitments, others were ambitious but limited in implementation opportunities, for instance due to geographical and legal limitations. As a result, uneven distributions of energy transition developments take place, causing other challenges that are more political – when, one municipality produces energy for another without anything in return, they are likely not motivated for making regional commitments (van Dijk et al., 2014). This is highly problematic for reaching a regional agreement, especially when ambitious policymakers are limited from a higher level (such as municipal coalitions) which *"restricts renewable energy within a large part of their jurisdiction"* (van Dijk et al., 2014, p. 101). Finally, the authors found that the role of provinces within a regional energy transition can be unclear, as the province both takes in an equal position to municipalities within regional discussions, while it represents provincial interests (which are guided by provincial responsibilities) at the same time. Arguments by Walker (2022) give insightful additions to the debate; however, van Dijk et al. (2014) show that the processes behind regional distribution of energy infrastructures are more nuanced, and a combination of the territorial and socio-political perspectives will provide more clarity regarding regional energy transition governance. Therefore, the analysis of energy infrastructure projects that span across multiple jurisdictions and involve a multitude of actors on different governance levels can provide chances to better understand the mechanisms behind the coordination between these levels (Goldthau, 2014).

In conclusion, several research gaps in understanding energy transition governance within metropolitan regions have been revealed. These include a lack of clarity on the roles and responsibilities of actors in metropolitan governance structures, especially in the absence of a leading actor with a formal mandate. Additionally, there is a need to investigate the impact of regional agenda priorities and collaboration levels among main cities and peripheral areas on energy transition development. Furthermore, there is limited research on the interplay between governance structures, socio-technical dimensions, and territorial perspectives in shaping energy transition outcomes within metropolitan regions. This chapter has identified research gaps in which both institutional arrangements and nexus governance topics are underrepresented in current literature. Therefore, I aim to shed more light on these topics in my research. In the next chapter, a conceptual framework will be designed to support this aim.

3. Theoretical framework

The literature review of this thesis has shown us the complexity of governing socio-technical energy transitions. It has highlighted the important and influential role that institutional arrangements play on different policy levels and across sectors for governing the energy-water nexus. Institutional arrangements decide the rules-of-game within which stakeholders in the energy and water sectors act and can be barriers or motivators for a successful energy transition towards a gas-free society. This research aims to explore the institutional barriers for the application of aquathermal energy within its case-study, and the next section will discuss the IAD framework as supporting theoretical framework that will be used to support this aim.

3.1. The IAD framework

The aim of the IAD (Institutional Analysis and Development) framework, introduced by Elinor Ostrom, is to *"identify the major types of structural variables that are present to some extent in all institutional arrangements, but whose values differ from one type of institutional arrangement to another."* (Ostrom, 2011, p. 9). The framework, originally to investigate the influence of institutions in collective choice processes (Ostrom, 2005), has been widely applied throughout research on institutional analyses and is suited for use in any type of social challenge on any level (Kimmich et al., 2023). The IAD framework is also particularly suited for this research. Where we have defined governance as *the interplay of actors and institutions as well as structures and processes* (Benz & Dose, 2010, p. 27) in the previous chapter, the IAD framework is designed to uncover just that. Moreover, the aim of this research to uncover the institutional barriers within energy-water nexus governance fits in the IAD framework approach too: it provides a systems perspective, and it helps to identify system features and their interrelations (Märker, 2022), for example between sectors. Next to that, it is effective for the analysis of nexus governance seen the focus on institutional dimensions of resource management challenges (Marker, 2021). This is in line with what Warbroek et al. (2022) argue on the IAD framework: it assists in recognizing the foundational categories of variables within institutional arrangements, making it particularly useful for studying institutions across different sectors. Based on that, Warbroek et al. (2022) note that the IAD framework offers a way to understand how institutions may form a barrier for nexus governance across scales and sectors. It assists in identifying relevant questions about important variables, like identifying key actors, understanding the rules that influence or restrict their behaviour, and assessing the impact of material and institutional conditions on them. Therefore, the main goal of the framework is not to provide solutions or answers to the specific problem (Märker, 2022).

In order to explain the framework and its components, we will look at the IAD framework as adapted from Ostrom by Märker et al. (2018). I am using this interpretation as, similarly to my research, Märker et al. aim to point out the institutional barriers in nexus governance. While multiple different variations of the framework exist due to its evolution and modification (e.g. Märker et al., 2018; Milchram et al., 2019; Warbroek et al., 2023), the essence remains the same.

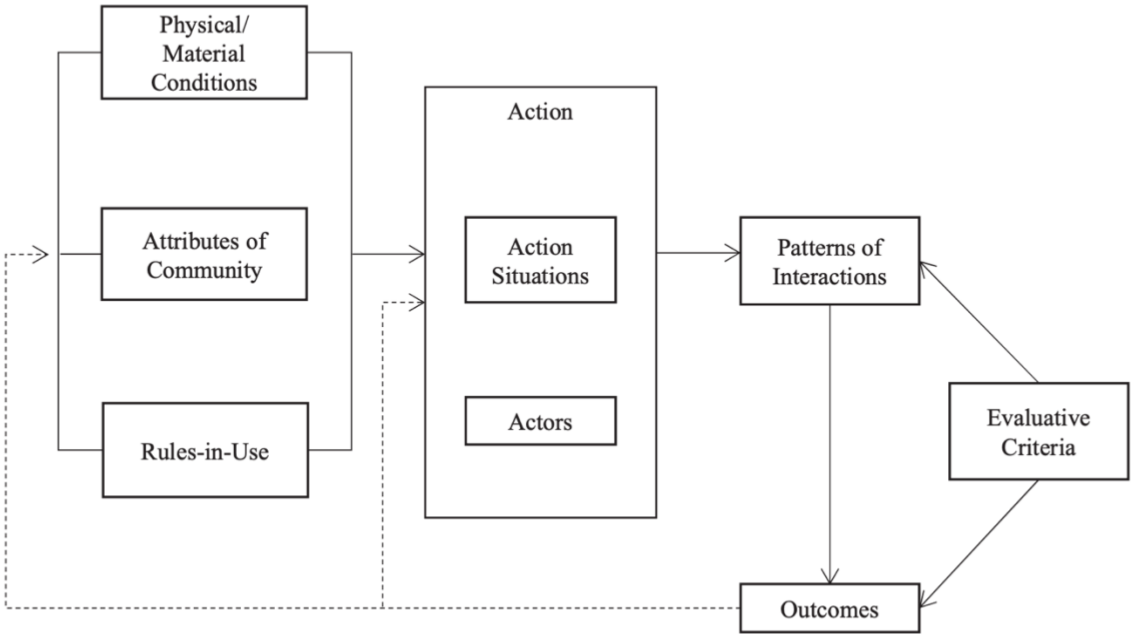

Figure 1: the IAD framework, as adopted from Ostrom by Märker et al. (2018).

3.2. Elements of the IAD framework

Essentially, the IAD framework consists of three elements that represent the functioning of the institutional arrangements that are in place. Firstly, as illustrated in Figure 1, the external variables on the left, secondly the action arena including action situations and the actors within in the middle, and thirdly the resulting patterns of interactions, their outcomes, and their assessment on the right (Märker, 2022). Next, these will be described in more detail, starting with the external variables.

Physical/Material Conditions

These are used to describe the physical environment of an action situation, and cover aspects like natural resources, infrastructures, and technologies that are present (Märker, 2022).

Attributes of Community

These attributes characterize the societal conditions that influence the actors within action situations. For instance, these can be the norms and values (Märker, 2022), the socio-economic circumstances (Märker, 2018), or the way in which sectoral policy implementation is arranged (Warbroek et al., 2023).

Rules-in-Use

The rules-in-use are a description of the institutional arrangements influencing action situations. This is a combination of formal and informal rules, which differ in the former being legally binding, while the latter are collectively agreed upon (Märker, 2022). The rules-in-use are dependent on the way in which institutions have developed over time, and it is argued that the alignment of formal and informal institutions is crucial for effective governance (Pahl-Wostl, 2009). The rules-in-use can also be seen as the vertical distribution of policies, for example through institutionalized sustainable development strategies and other action reports (Märker et al., 2018). The interpretations and understanding of the rules-in-use can differ between actors, leading to them not being followed (Al Masri, 2021).

The three external variables that were explained are incorporated into the IAD framework as they recognize and allow for the analysis of place dependent situations. Combining them paints a full picture of a case: the outcomes of cases with similar physical attributes may still differ very much, as they are influenced by the institutional context in which actors operate. Therefore, the IAD framework displays the performance of context-specific governance and institutional analysis (Al Masri, 2021). The characteristics of the remaining framework that are the results of external variables will now be discussed.

Action situations

Action situations describe the spaces in which actors interact and generate outcomes. This is the most important, central, 'focal' point of the IAD framework (Ostrom, 2011; Märker, 2022; Märker et al., 2018). It is the first element that research looks at to identify the involved actors and to explore the space in which they interact. Depending on the research goal, action situations can be analysed at different political levels and policy-making stages, and at one moment in time or over a period of time (Märker, 2022). Analysing action situations helps to *"understand the behavior of and dynamics of interaction among the different actors (the 'actors' component) within preset institutional arrangements and practices (the 'action situation' component) to investigate and propose collective actions and outcomes."* (Al Masri, 2021).

Actors and interactions

The actors within an action situation can be individuals or actors representing involved groups. As institutions are represented within the rules-in-use, it is not institutions that act within action situations, but rather relevant individuals and organisations (Märker et al., 2018). Ostrom (2011, p.13) portrays actors as *"fallible learners that can make mistakes and are able to learn from them"*, the degree of which is influenced by the external variables. Moreover, the element of interaction aims to describe how actors interact, and sheds light on the coordination between them within action situations. This makes the IAD framework suitable for small-scale analysis of action situations (Ostrom, 2011, p.10).

Outcomes

The outcomes are the results that flow from action situations. The meaning of these depends on the research focus, as some research focusses on the interactions within action situations rather than the outcomes of them. Analysing the outcomes of action situations can indicate the functioning of a political system (Polski & Ostrom, 2017).

Evaluative Criteria

The evaluative criteria assess the outcomes of action situations, for example by looking at the efficiency, sustainability, and institutional flexibility and adaptivity of the outcomes (Ostrom, 2011). These insights can help identifying the barriers that institutions pose on actors within the water-energy nexus and give suggestions to where and what change is needed.

3.3. IAD framework application in nexus research

The IAD framework has been used for a variety of purposes in research. Its application has also produced relevant insights into nexus governance. This section will describe the approach of a selection of relevant studies that adopted the IAD framework, after which the selection of approaches that will be used as framework for this research is clarified.

Firstly, Märker et al (2018) used the IAD framework to address the need for institutional change towards nexus governance, for which they used the framework to underline the importance of the role of interaction between actors and institutions. They define the rules-in-use as the current institutional arrangements, while organisations function as actors in action situations, and primarily look at the outcomes of action situation and their effects on other action situations (Märker et al., 2018). For them, the institutional arrangements are decisive for governance processes and policy integration. Furthermore, they create new models representing horizontal and vertical coordination. Respectively, they aim at and underline the importance of policy integration between nexus sectors (horizontal) and the policy integration on different institutional levels (vertical). They do this by placing the IAD framework within the Management and Transition Framework (MTF), which provides them with insights as to how to achieve policy integration (Figure 2).

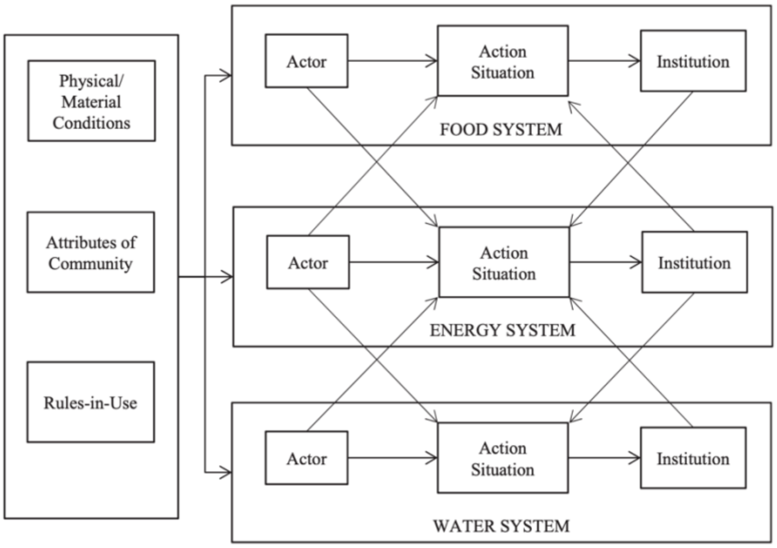

Figure 2: Full nexus cooperation framework (IAD framework modified based on Ostrom by Märker et al. 2018).

Secondly, Kimmich et al. (2023) review different IAD framework applications by scholars and explain Network Action Situations (NAS) that the IAD framework produces. The beforementioned MTF is described as a precursor, which first recognised that outcomes of an action situation affect the process of following action situations (Kimmich et al., 2023). However, McGinnis (2011) developed NAS as an extension to the IAD framework by conceptualising adjacent action situations as having relationships across governance levels and sectors (Kimmich et al., 2023). This is highlighting the interdependence of nexus sectors, as Kimmich et al. (2023, p. 14) explain: "*this interdependence can span sectoral boundaries, for example, when action situations in the energy sector are linked to action situations in the water sector through shared resources.".* Bridging towards the next paragraph, Warbroek et al. (2023) mention NAS as an effective way in uncovering the (missing) institutional arrangements that make nexus integration between sectors difficult. Following this line of argument, the NAS concept can help to identify the relation between sectoral action situations, in combination with the IAD framework this can help explain the institutional barriers that exist.

Thirdly, Warbroek et al. (2023) use the two previous applications on their case study regarding the energy transition in the province of Overijssel (Netherlands). Using the IAD and NAS frameworks as a basis, they argue that the interaction between sectors is highly dependent on institutional arrangements and actors within action situations have difficulties in achieving integrated coordination between energy transition sectors. Warbroek et al. (2023) establish the analysis of action situations, which are structured by the following seven rules by Ostrom (2011): 1) *Position rule:* what positions and roles actors have; 2) *Boundary rule:* how actors can participate; 3) *Choice rule:* what actions they can take; 4) *Information rule:* how information is shared; 5) *Scope rule:* what the scope of the outcome is; 6) *Payoff rule:* how costs and benefts are distributed; and 7) *Aggregation rule:* how decisions are made.

These rules that shape the outcomes of action situations can be analysed from different levels: Warbroek et al. (2023) argue that in current research there is a lack in understanding of the role of institutions influencing integrative nexus coordination from an operational level, thus choose this level as an approach to uncover the institutional barriers experienced by energy transition actors. They then explore the degree of integration between action situations, for which the authors look at vertical and horizontal integration. Integrative action situations are *"action situations in which actors from diverse sectors collaborate to explore and potentially exploit the integrative potential of solutions to interconnected societal challenges"* (Warboek et al., 2023, p. 101). Vertical integration looks at the coordination between institutions at different spatial scales, while horizontal integration looks at the coordination between sectors. Figure 3 represents their results, having used their data as input for the IAD framework, and 'comparing' sectoral action situations through NAS.

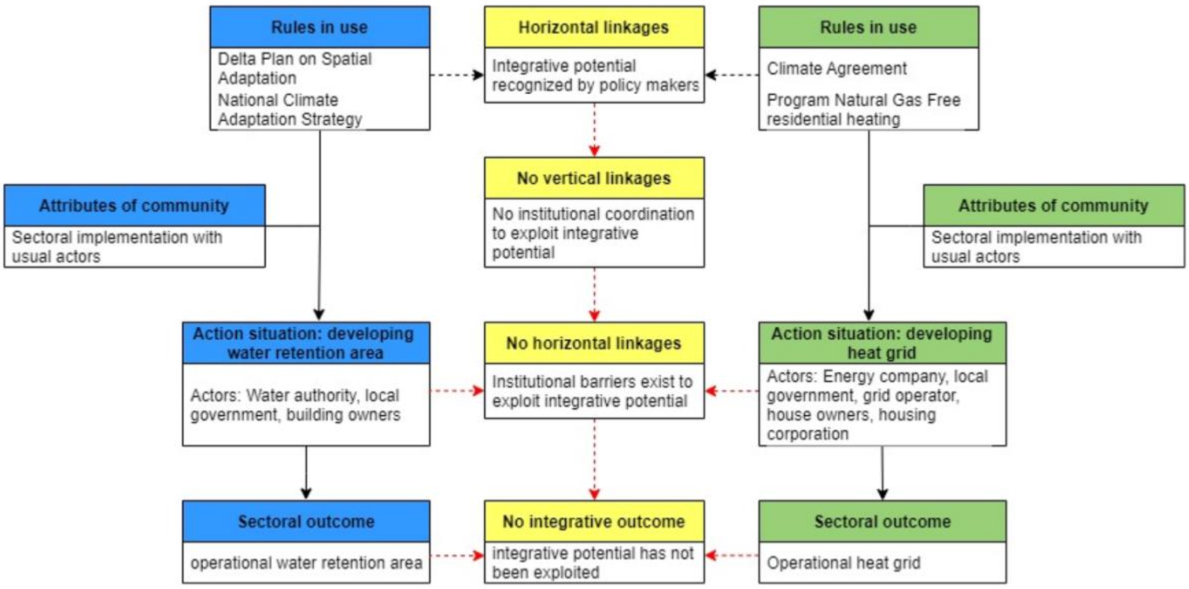

Figure 3: Degree of integration between action situations (by Warbroek et al., 2023).

3.4. Adopted approaches for this research

While the approaches in the previously discussed studies all utilize the IAD framework, it shows that a different focus can be applied together with different goals for the outcomes of studies. Therefore, it is important for this thesis to narrow down the relevant approaches of the IAD framework that we will use as a basis for analysis.

The aim of this research is to address institutional fragmentation that hinders the implementation of water-energy nexus solutions, specifically aquathermal energy. It will do so in an exploratory manner, meaning that it aims to uncover institutional fragmentation and how to address this, but will not directly aim at solving integration issues for successful implementation. This thesis sees institutions as the most important factor influencing the rules of the game and nexus-coordination. Therefore, it will follow Märker et al. (2018) in emphasizing this importance. However, Märker et al. strongly focus on the outcomes of action situations and, by doing so, aim to discover how horizontal and vertical policy integration can be achieved via IAD models. This research takes a different approach. While it recognizes the importance of focussing on horizontal and vertical coordination, it aims to analyse institutional barriers within action situations, which is where it lays its focus. Looking at interactions within action situations will shed light on how the external variables influence the behaviour of stakeholders and the degree of vertical and horizontal coordination. It will follow the approach by Warbroek et al. (2023) by looking at coordination on the operational level, as little is known here about institutional barriers.

While recognizing their value, this thesis will omit Ostrom's seven rules (Warbroek et al., 2023; Ostrom, 2005) from data analysis. Instead, it will add a fourth external variable to the IAD framework, namely the 'spatial context' which incorporates the complexity of governmental and sectoral jurisdictions within the case study area. Together, these will allow for the analysis of action situations and actor coordination, as well as lay the basis for expert interview approaches. Next to this, the NAS approach by McGinnis (2011) as explained by Kimmich et al. (2023) will be recognized, seen the multi-sectoral character of aquathermal energy governance. The NAS approach will allow for the understanding of cross-sectoral perspectives and coordination, from which the degree of and barriers for integration due to institutional settings can be obtained. This approach results in the IAD framework as shown in Figure 4.

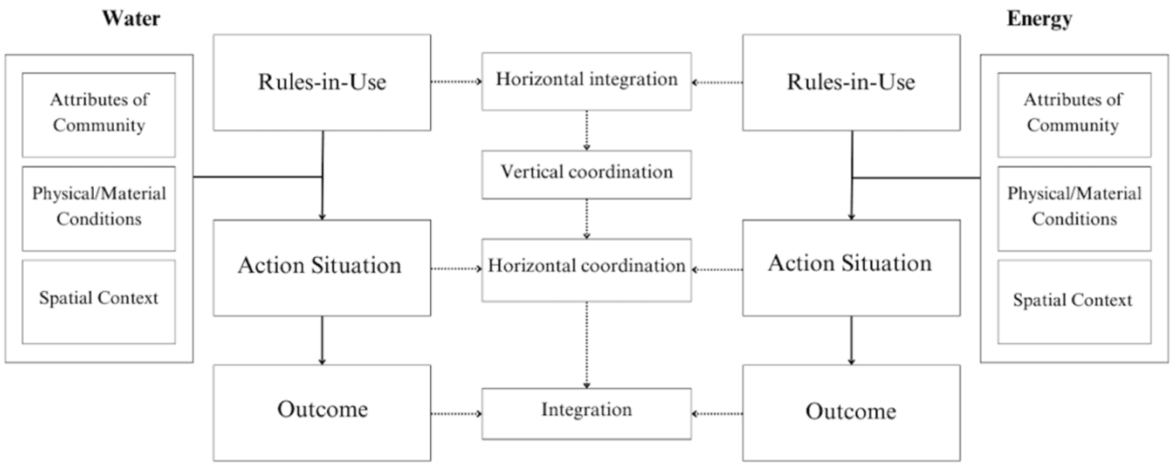

Figure 4: IAD framework visualising coordination between sectors influenced by external variables. Own adjustment, based on Warbroek et al. (2023).

4. Methodology

This section will provide an overview of the reasoning behind and the execution of the methodology that was used for this research to address institutional fragmentation in aquathermal energy governance in the Metropolitan Region of Amsterdam, as well as the ethical considerations that were made during data collection.

4.1. Qualitative case study approach

To support the research aim, this study used a qualitative case study approach consisting of two types of qualitative data methods: document analysis and expert interviews. Case studies are an effective research method to study complex phenomena that occur in specific settings, to gain a better understanding of them (Heale & Twycross, 2017). Additionally, a qualitative approach helped to identify complex underlying processes (Clifford et al., 2016). Therefore, it was found a suitable method to carry out an intensive study on the complexities of aquathermal energy governance in the MRA. A benefit of the application of a qualitative case study was that it helped in understanding the coordination between stakeholders within institutional settings and highlighted how these are influenced by the distinctive context in the case study area. It allowed for the exploration of settings and experiences that could be hard to understand through other research methods and was effective in revealing insights from involved stakeholders that might otherwise have been overlooked (Lee & Saunders, 2017).

A single case study approach also presented its limitations. Seen the focus on specific processes in a specific metropolitan area, the data gathered through this case study are not generalisable and cannot be directly applied to other metropolitan areas for which underlying factors influencing the results most likely differ. Next to that, replicating this case study may not lead to the same outcomes as underlying factors may have changed, or new ones could be discovered. Another limitation that needs to be mentioned is one in comparison with a multiple case study, in which findings can be compared and related between cases, making for more reliable research (Gustafsson, 2017). However, the choice for a single case study has resulted in a more detailed understanding of processes by studying a selected group of stakeholders in the MRA.

The selection of the MRA as case study is relevant because of the regions' leading position in the energy transition, with the MRA being selected as a frontrunner in circularity by the European Commission (MRA, 2022), aiming to realise a shift to a circular economy by 2050 which includes the circular use of energy sources, such as using heat from (waste)water. Furthermore, policy decisions in the Netherlands are made at national, provincial, and municipal levels. Informal governance arrangements are active on the metropolitan level and influence the formal decision-making and spatial development (Heurkens & Dąbrowski, 2020). This makes these relations within the region an interesting study topic. Furthermore, the metropolitan region is a justified case study because of its high availability of waterbodies containing heat, spanning across unique spatial settings with a multitude of involved stakeholders that present complicated governance questions. As this research shows, while the sources are available, there seems to be fragmentation in governance between sectors and across the jurisdictions within the metropolitan area. Next to that, the region is densely populated with its population still growing, leading to an increased energy demand during the energy transition. These reasons, thus, signify the need to understand the governance dynamics surrounding aquathermal energy use. Lastly, with the MRA being a leading region in energy transitioning, the focus on this case study could provide relevant insights for other regions within the country or abroad. While keeping in mind that its case-specific nature is not fully generalisable, it could still indicate ways in which stakeholders can coordinate, and what is expected from institutions to accommodate this.

4.2. Data collection

4.2.1. Expert interviews

As there is a multitude of actors involved, ranging from different levels of institutions to actors in different sectors, semi-structured problem-centred expert interviews were conducted (Döringer, 2020) to gain insights from multiple perspectives on the coordination processes influenced by institutional settings regarding aquathermal energy application. The choice for semi-structured interviews was made as it allowed for the deviation from pre-determined questions when desired, compared to structured or unstructured interviews which can miss out on relevant data by having no or too much flexibility (Hay and Cope, 2021; Clifford et al., 2016). The interviewee selection process had as aim to be as inclusive as possible to gain representative insights, and criteria were based on the involvement in the MRA, and an equal distribution between different governmental levels, water and energy sectors, and public and private perspectives. A total of eight interviews were conducted with nine interviewees (Table 1).

The water sector was represented by an advisor on the energy transition at the national Department of Waterways and Public Works, a strategic advisor on the energy transition for a regional water organisation, and a technical advisor on the energy transition for a regional waterboard. Next to that, interviewees active in the energy sector included the chairman of a citizen-initiated heat co-operation, a senior business developer at a public-private company, and a business development manager at a private energy company, complemented with a project manager functioning as an overarching actor between water, energy, and housing sectors. Lastly, a strategic advisor on sustainability and the energy transition active at a municipality was interviewed, who was closely involved with and accompanied by an advisor and program manager active in the (private) consultancy sector supporting municipalities. These stakeholders were all active on aquathermal energy application in the case study area and represent vertical and horizontal relations, as well as public and private sectors. Although actors on municipal, waterboard, and national level could provide useful insights in the role of the province, a planned interview with a public actor active at the provincial level could unfortunately not take place.

The semi-structured interview guide (Appendices A & B) had one standard format but was adjusted during interviews according to the expertise of different interviewees. This has supported the research aim and questions to the fullest (Roberts, 2020), and provided insights on topics from different perspectives. The interview questions were based on and followed the structure of the external variables as presented in the theoretical framework (physical and material conditions; attributes of community; rules-in-use). A fluid approach was followed during this research (McArdle, 2022). This flexibility assured the preparedness for change during the research when the understanding of the topic increased or changed. This resulted in the addition of a fourth external variable: spatial context. As can be observed from the interview guide, this variable has not specifically been assigned a section of the interview questions. However, insights into this variable were obtained through the discussion of territorial coordination with interview respondents.

Interviewee no.	Function	Organisation	Date	Reference
1	Strategic Advisor Energy Transition	Public: Waterboard	08/05/2024	R1
2	Chairman	Citizen initiative: Local heat cooperation	16/05/2024	R2
3	Project manager	Freelance: Heat, water & housing sector	17/05/2024	R3
4	Advisor Energy Transition	Public: National Department of Waterways and Public Works	27/05/2024	R4
5	Senior Business Developer	Public-private: Energy sector	28/05/2024	R5
6	Business Development Manager	Private: Heat sector	29/05/2024	R6
7	Technical Advisor Energy Transition	Public: Waterboard	30/05/2024	R7
8	Strategic advisor sustainability/energy transition	Public: Municipality	30/05/2024	R8
9	Advisor and Program Manager	Private: Consultancy, municipal support	30/05/2024	R9

Table 1: List of interview candidates, including function, date, and in-text reference. Own table.

4.2.2. Document analysis

Next to the expert interviews, systematic document analysis was carried out to provide background and context to the settings in which stakeholders operate. Documents include laws and policies and their approaches on national level (and its relation to European level), provincial level, regional level, and municipal level. Furthermore, other documents such as newspaper publications and reports on the case study and research topic were included. The document analysis can be explained in several steps. First, it was studied how laws and policies surrounding water and energy have evolved on the nation level, until the first notion on the potential of aquathermal energy. It was then reviewed how these were combined and translated into provincial, regional, and municipal strategies. All documents were thoroughly scanned on information regarding the research topic in combination with the theoretical framework. This process has provided extensive knowledge both on the case study area and its involved stakeholders, as well as in understanding the origins of the context provided by the interview respondents. Understanding this context has also served as the basis of several interview questions, as well as for the ability to engage in substantive follow-up questions.

4.2.3. Data analysis

After having received consent from interview respondents, all interviews were recorded using a personal mobile device and/or online meeting software. Subsequently, the recordings were manually transcribed, and the transcripts were imported into NVivo 14 for analysis. The transcripts underwent thematic analysis, including multiple steps to arrive at a satisfactory coding scheme. First, familiarization with the data took place, after which initial codes were assigned to text fragments. When all interviews were conducted, themes were searched for, reviewed, defined, and confirmed (Clarke & Braun, 2013). In this research, a part of this process was repeated as a new variable was added to the theoretical framework, and codes were reduced and improved when the understanding of the matter changed. The final coding scheme can be found in Appendix C. As can be seen there, the codes were based on the four external variables as per the theoretical framework that was used for this research. A combination of inductive and deductive coding was used, as some themes and codes were expected to be found based on desk-research (deductive). Other codes were created based on the insights obtained from interview data (inductive) (Verhoeven et al., 2023). The codes provided the overview needed to give further meaning to the data and identify patterns and relations that helped answering the research questions.

4.3. Ethical considerations

During all steps in this research, ethical considerations were a central point of attention. Potential interview respondents were approached via the researchers' private university email address with an invitation email clearly stating the research topic, purpose, and the reason why this email was sent. During contact, the freedom was given to the respondents regarding the location and date of the interview, and voluntary participation was assured. Before the start of each interview, respondents were informed about its structure. Consent was received from all participants regarding the recording of the interview, and the processing and usage of the data for this research. It was explicitly mentioned that all information is treated anonymously, confidentially, and stored in a password-locked location only during the research process. All respondents were treated equally and respectfully and there have been no conflicts of interest. Trustworthiness and reliability of the research outcomes have been safeguarded by processing responses in the exact way that they were said and meant, without projecting possible biases on the results that could result in different storylines (Mirza et al., 2023).

5. Results

This chapter will discuss the results derived from the qualitative data obtained during this research by deploying the theoretical framework. The framework will be used to systematically provide insights into the external variables that were studied. Before discussing its variables, the section will start by giving an overview of the Metropolitan Region of Amsterdam, its water and energy systems, and the institutional arrangements promoting aquathermal energy use.

5.1. Introduction to the case study

The Metropolitan Region of Amsterdam (MRA) is located in the densest populated areas in the country, the Randstad, in the Western part of the Netherlands. Situated in the bottom half of the province of North-Holland and the Western part of the province of Flevoland, it accommodates 30 municipalities housing two point five out of the close to eighteen million inhabitants of the Netherlands (MRA, 2024; CBS, 2024a). Next to the provinces and municipalities, the MRA is subdivided in seven sub-regions (Amsterdam, Amstelland-Meerlanden, Zaanstreek-Waterland, Almere-Lelystad, Zuid-Kennemerland, Gooi en Vechtstreek and IJmond), two energy regions, and four waterboards. The MRA functions as the growth engine for the national economy, supported by two airports, seaports, many companies facilitating one point five million jobs, and the nation's financial centre. The region strives to be internationally competitive and attractive with excellent infrastructures connecting to its surrounding rural areas as well as other countries. Within the region, there is a high degree of interconnectedness and interdependencies, where actions in one jurisdiction influence other jurisdictions. Current day challenges, therefore, are highly complex in nature and require a regional approach. Authorities of the MRA define the region's success through the history of collaborations and interactions between its cores (MRA, 2024). Today, this is being continued through the MRA Agenda, which has two leading goals: a future-proof and well-balanced metropolis. The agenda includes the stimulation of market initiatives for transition challenges and energy infrastructures, for instance the development of aquathermal energy use. The national government and the involved waterboards are said to be important actors in achieving set goals (MRA, 2024).

With its many lakes, rivers, and canals, the MRA has a large availability of water. With water covering 35% of Amsterdam's surface area (Gemeente Amsterdam, 2021), water systems play a significant role in the functioning of society in the MRA. They are used to fulfil basic human needs, for recreational purposes, the irrigation of agricultural land, and for trade. Due to climate change and extreme weather, the water systems are under pressure and in need of effective management (Gemeente Amsterdam, 2023b). The water systems are managed by four waterboards (Hoogheemraadschap Hollands Noorderkwartier, Hoogheemraadschap van Rijnland, Waterschap Amstel, Gooi en Vecht, and Waterschap Zuiderzeeland). The waterboards take on tasks concerning the (drinking) water quality, treatment, and water level management within their assigned territories. The waterboard spanning across the largest area of the MRA, Waterschap Amstel, Gooi en Vecht, has assigned Waternet as public operating company for in and around the city of Amsterdam. Where waterboards manage regional waters and wastewater, the Waterboard Law assigned the management of larger water bodies like lakes and rivers to the National Department of Waterways and Public Works (Rijkswaterstaat, n.d.). Combined, these waters hold large potentials for aquathermal energy: in the province, 96% of the built environment can be heated through aquathermal energy from surface water, next to 2% from wastewater (MRA, 2020).

The energy systems (electricity and heating) in the region are managed through energy region North-Holland South, which follows the spatial borders of the MRA except for the province of Flevoland (which has its own energy region). The energy region North-Holland South is divided into six sub-regions and can include multiple municipalities (Image 3). As current energy systems are still largely powered by fossil fuels, each sub-region is looking at the best solutions to make their energy systems sustainable (Energieregio NHZ, 2021a). Sustainable energy solutions often mean a shift from fossil fuelled heat generation to individual solutions powered by electricity. As the MRA is densely populated, large scale application of individual heating solutions can cause grid congestion, and slow down the energy transition (MRA, 2023). The current focus for development is on collective heat solutions like heat networks. These are currently present in the MRA (mainly Amsterdam and Almere) but are not supplied with sustainable heat sources (Gemeente Amsterdam, 2023a). Current heat networks need to be extended and made sustainable, and new networks need to be constructed to fulfil the heat demand of the MRA. Aquathermal energy is one of the potential sources to use for heat supply in the existing and new heat networks (Gemeente Amsterdam, 2023a).

To realize the potentials of aquathermal energy usage, the water and energy systems in the MRA that are now largely separated systems are in need for integration. The institutional arrangements that are promoting aquathermal energy usage are found in the Dutch Climate Agreement, which states a 49% CO_2 reduction in 2030 compared to 1990 as aim (Rijksoverheid, 2019). Included in the climate agreement is the focus on governance, cross-sectoral infrastructure integration and the importance of exploring aquathermal energy potentials for its scaling within regions. In 2019, this was translated into the Green Deal Aquathermie, which was meant to give insights into the possibilities and scaling of aquathermal energy use. On the regional level, agreements on aquathermal energy sources are made in Regional Energy Strategies and passed down to municipalities, which are then supported by the Expertise Centre for Heat via which knowledge is shared. The aim is to integrate the Expertise Centre for Heat with the Expertise Centre for the Energy Transition over time, to create synergy benefits (Rijksoverheid, 2019).

5.2. Physical and Material Conditions

Aquathermal energy sources are abundant in the MRA, as Waternet (2024a) has mapped for the municipalities in the region (Figure 5). Aquathermal energy from wastewater is mostly present locally, with its potential sources being sewage systems and wastewater treatment plants. Aquathermal energy from surface water is found locally in city waters, but also has large potentials in intra-municipal sources like rivers and lakes (Energieregio NHZ, 2021b; R4). *"Forty percent of the built environment in the Netherlands can be provided with aquathermal energy, twenty percent of which is from national waters."* (R4). For the MRA this percentage is higher, with the province indicating 96% of the built environment (MRA, 2020) and interviewees indicating potentials of 60% of the total energy demand.

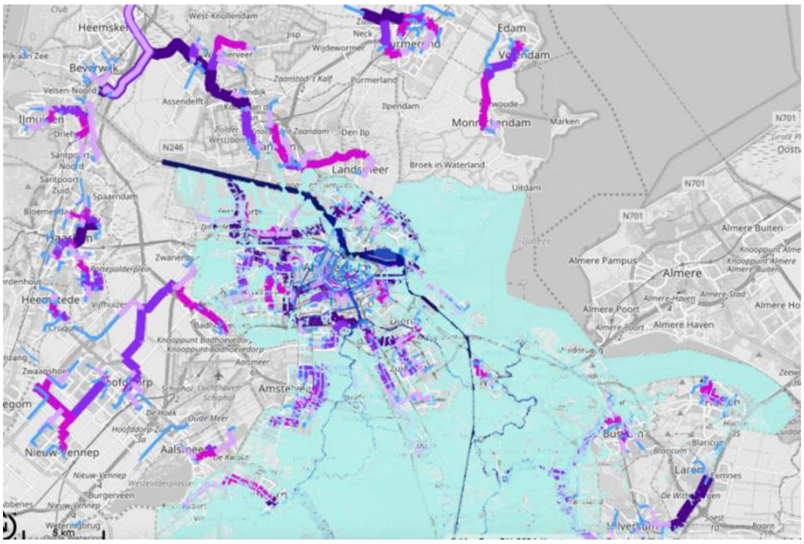

Figure 5: Aquathermal energy source locations within MRA, with surface water in blue and wastewater in pink. A darker color means more heat potential. Source: Waternet (2024a).

The aimed usage of these sources is decided upon in Heat Transition Visions, the municipal input for the Regional Energy Strategy in the MRA, which considers the most suitable sustainable heat options per neighbourhood (Over Morgen, 2020). These considerations are based on the lowest societal costs and nuisance, the existing infrastructures that are in place or have been planned, the available heat sources, and the degree of sustainability. While much potential for aquathermal energy from surface water is present in the canals of the inner city of Amsterdam, the vulnerable historic constructions and underground spatial limitations do often not allow for aquathermal energy usage, given that the construction of heat networks is needed for this. Spatial limitations are seen as a common challenge for the development of sustainable developments, as is mentioned in the Circular Economy Agenda 2021-2025 (Provincie Noord-Holland, 2021). Multiple respondents also mention the underground spatial limitations, especially in Amsterdam: *"Space is limited, especially in Amsterdam. This means making choices between the best heating solutions, but also the best solution compared to parallel* *implementations that need space too. This makes it extra complicated"* (R9). As there is no sufficient underground space for multiple heat networks, the municipality has the aim to integrate energy systems, making them open networks to which different energy sources can be connected.

Multiple interview respondents indicate the possibility of the integration of aquathermal energy with the existing heat infrastructures that are present in the MRA. The heat networks currently present in the MRA are mostly supplied with non-sustainable heat sources like waste incineration (Gemeente Amsterdam, 2023a), with the exception of aquathermal energy-based heat networks operated by citizen-initiated heat co-operations like Wattnu in Muiderberg (NH Nieuws, 2024). While the integration of aquathermal energy with existing heat networks is desirable according to the municipality of Amsterdam and multiple interview respondents, heat networks in the MRA are mostly privately owned (Figure 6). Their current energy infrastructures will need to be redesigned to make the transition from fossil to renewable energy sources possible, and integration can be difficult due to the investments made by the private companies for the development of the network. They will protect this out of competitive considerations, to prevent sunk costs and to keep control over their network.

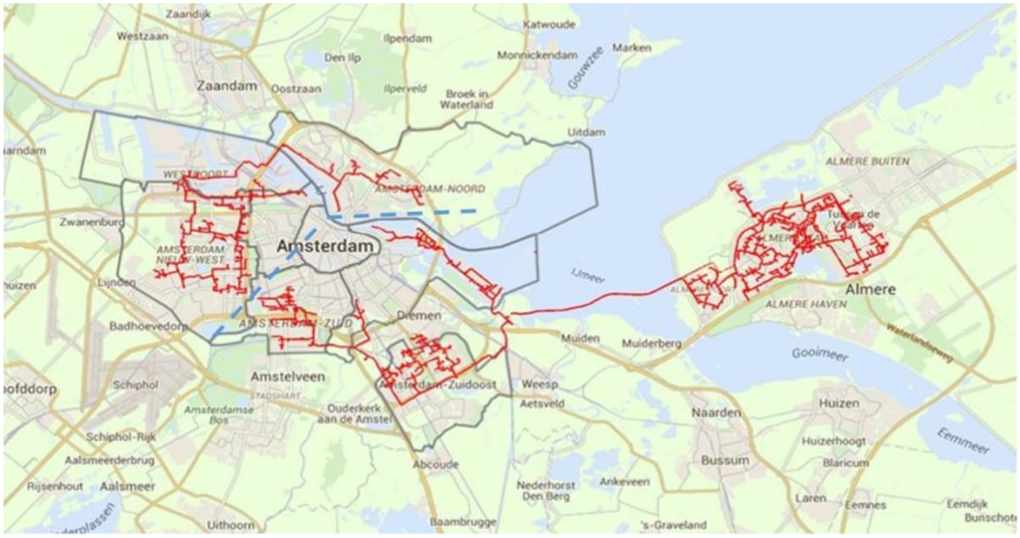

Figure 6: Current (mostly) privately owned heat network, in and between Amsterdam and Almere.
Source: CE Delft (2019).

In Amsterdam, the heat network does not span across all neighbourhoods assigned to heat network connection, meaning that new heat networks need to be constructed for the built environment. While some respondents and the municipal policy (Gemeente Amsterdam, 2020) indicate the desire for integration of aquathermal energy into existing heat networks, other respondents argue that separate heating infrastructures are needed for aquathermal energy usage. While the possibility for aquathermal energy integration is recognized, current heat networks operate on high temperatures while aquathermal energy sources provide low temperatures. Having to upgrade the temperature of these sources would always be the best option:

> We could also supply to these (existing) networks. However, we would need to upgrade the temperature with heat pumps multiple times, which is a waste. It is better to use low temperatures for well-insulated residences. (…) This always results in new heat infrastructures." (R1)

These low temperature networks are mainly suitable for the supply to insulated buildings built from 1995 (R1; Over Morgen, 2020).

Where the discussed physical and material conditions mostly influence the integration of aquathermal energy from surface water, wastewater heat sources can face different challenges for integration. Using heat from wastewater before its treatment can influence the biological treatment process when sewage systems. As current sewage systems often do not have enough volume, making many locations unsuitable for heat extraction: *"For wastewater, this is certainly a factor. Extracting heat from the influent can influence the treatment process. (...) These projects are hard to realise."* (R7). The heat from the effluent (wastewater after being processed in a treatment plant), however, has real potential for usage. Here, a physical implication is found in the distance from a wastewater source to residences or an integrated heat network. While one kilometre is viable for maintaining heat, only 200 meters is economically feasible, influencing the location selection. With the limited number of wastewater treatment plants and their placement often relatively far from residential areas, other heat sources are often more favourable for integration. However, the locations of treatment plants in the Northern area of the MRA show potential for aquathermal energy from wastewater, as was confirmed by an interview respondent active in the waterboard active in this area (R6).

5.3. Rules-in-Use and Attributes of Community

5.3.1. Policies and regulations

In the Netherlands, formal policymaking takes place at the national, provincial, and municipal institutional levels (Heurkens & Dąbrowski, 2020). The policy frameworks surrounding the application of aquathermal energy in the province of North-Holland, in which the MRA is situated, are found in the goal to be climate neutral by 2050 that the Dutch state took over from the Paris Climate Agreement in 2015 (Provincie Noord-Holland, 2022). The goal for 2030 is set to achieve a reduction in CO_2 emissions of 55-60% compared to 1990. The application of aquathermal energy concerns the nexus between water and energy systems, thus bringing together policy frameworks of both sectors.

On the national level, the frameworks surrounding water systems have been shaped by the Ministry of Infrastructure and Water Management and the Union of Waterboards. The Water Law in 2009 includes the management of full water systems, except for drinking water supplies and city level sewage system management which are included in the Law for Drinking Water and the Law for Environmental Management (Unie van Waterschappen, 2021). Furthermore, the tasks and territories of waterboards are decided in the Law for Waterboards. In 2018, Water Agreements included the ambitions of water managers in the energy transition for the first time, mentioning the potentials of thermal energy extraction from surface water (Rijkswaterstaat and Unie van Waterschappen, 2018). All water policies relevant to aquathermal energy promotion have now been integrated into the Environment and Planning Act. Energy system policies have developed within the current Gas Law and Electricity Law from 1998, which is undergoing a renewal process to better support the energy transition (Rijksoverheid, 2022). Heat policies are found separately in the 2014 Heat Law, where the transport of thermal energy from renewable sources via water is mentioned, but in which water as a heat source is not specified (Wettenbank, 2014). The development of sustainable energy systems is being promoted by the national government through the Plan for the National Energy System. Here, the relation between heat and water systems is being recognized and aquathermal energy is specifically mentioned as an important future heat source. (Planbureau voor de Leefomgeving, 2023). A barrier that is mentioned in the national plan is regarding the current emissions through high electricity use for aquathermal energy: heat sources like waste incinerators currently have higher chances of complying with the strict sustainability norms that are in place. Interview respondents also indicate the prioritization of heat from waste incineration but mention a different reason:

> Where there is a waste incinerator with residual heat, this is much more affordable than using big heat pumps for low temperature aquathermal energy. With the latter, you will increase the price for end consumers. This is a consideration that you need to make. (R8)

The report, however, promotes aquathermal energy by emphasizing the need for a long-term focus, where aquathermal energy is said to likely evolve into a preferred heat source.

Next to the recognition of aquathermal energy in policies, there are governmental subsidies in place that promote its application, such as the SDE++ (Sustainable Energy Development), and the National Growth Fund (NAT, 2023). Granting these subsidies, however, can be a long and complicated process. According to European regulations, institutions need to act like private parties in order to protect market mechanisms, meaning that extensive research needs to be done on the profitability of projects before these can be financed (STOWA, 2019). This has a demotivating effect on the initiation of projects and slows down the energy transition. Moreover, subsidies include but are not yet tailor-made for aquathermal energy solutions. Where subsidies from the central government exist for heat network initiatives with a large number of connections, some projects work with big, single connections which provide heat to a full block of flats using aquathermal energy. When the criteria for a sufficient number of separate connections is not met, projects like these do not qualify for financial support. *"In fact, we have little connections as we work with collective connections. Not for every front door, but on building level. This is why we sometimes miss out, which is a big shame."* (R3). Furthermore, pilot programs that promoted aquathermal energy projects with subsidies are found to be discontinued. *"There is a need for national financial support from the start to make projects attractive. We used to have the Testing Grounds for Gas-free Neighborhoods. Such programs should be continued."* (R1).

National water and energy policies are passed down to the provincial level, on which aquathermal energy is included in provincial heat transition approaches (Provincie Noord-Holland, 2022). The focus of the heat strategy is on insulating existing homes and finding a suitable gas-free alternative for their heat supply. The report emphasizes that there is a multitude of different actors on different levels that are involved in the development of this transition, all of which have their own role and agenda. *The state* is mentioned as an important player, as it manages laws, financing and overall governance surrounding the heat transition. *The province* is the steering organ within the region: it connects stakeholder, finances pilot projects, and facilitates knowledge sharing. *Regions* are indicated as being the collaboration between municipalities, for instance where large potential heat sources (like aquathermal energy sources) can be used across municipal territories. At the same time, individual *municipalities* decide which transition measures can be used and how to gain support for this. Next to these governmental bodies, the *private sector* (heat, energy, and housing corporations) is recognized as being an important asset in the realisation of the heat transition, for instance by advising on, investing in, and designing developments. Together with municipalities and waterboards, provinces lobby for suitable heat and energy laws (Provincie Noord-Holland, 2022).

Where municipalities are assigned the directing role in the energy transition, municipal transition visions for the heat transition are connected in regional energy strategies (RES). For the Metropolitan Region of Amsterdam, this concerns the RES of energy region North-Holland South (Energieregio NHZ, 2021b). Its implementation has the aim to utilize the potential of intra-municipal heat sources, by stimulating intermunicipal collaborations for the development of supporting infrastructures, which also involves stakeholders in the energy sector. While regional waterboards partake in the RES and heat sources including aquathermal energy are recognized to be of importance, the main focus remains on development of wind and solar energy, which is also recognized by interview respondents. *"The focus needs to shift more towards heat sources. The energy transition is mainly focused on electricity, but two-thirds of the energy demand concerns heat."* (R4). Furthermore, interviewees confirm that all municipalities have indeed published their visions, in which there is looked at the heat solution with the lowest societal costs. However, these visions are said to still be in a start-up phase, in which actual implementations are not yet taking place on a large scale.

This is the case, while all respondents have a shared perception of the benevolent attitude of the involved actors to consider the implementation of aquathermal energy and to work towards the climate agreement in more general terms. *“Every time I see that different involved sectors are on the same page, and everyone wants to make the energy and heat transition a success, no matter how complicated it is.”* (R4). For the past years, municipalities in the MRA have been looking at ways to bring together these stakeholders, and interview respondents experience this start-up phase to be very long. An important reason for the slow development is that the legal frameworks to guide these stakeholders in aquathermal energy application are in development, according to the director of a heating co-operation initiated by citizens (R2).

Other respondents indicate to miss any organisation around the development of aquathermal energy. They see that the novelty of this area in which the municipality receives new tasks increases complexity and causes new debates. Within current legal frameworks municipalities are allowed to produce and supply heat through aquathermal energy, so a certain degree of flexibility regarding its application is found (NAT, 2019). However, there are no concrete frameworks in place for coordination between stakeholders (Energieregio NHZ, 2021b). *“The national government puts municipalities in a directing role, but municipalities do not have the instruments available to steer this process. It is a very difficult playing field for municipalities.”* (R7).

In the current situation where stakeholders are willing to contribute, a lack of clear direction in the energy transition from the national government is argued to be a barrier in the development of aquathermal energy. Municipal heat visions steer towards collective heat solutions, such as heat networks with aquathermal energy as a source (Gemeente Amsterdam, 2020). However, a mismatch is found in current national policy frameworks: current subsidies make individual heat solutions cheaper than the connection to a collective heat network with sustainable heat sources, while the latter adds more societal value (Binnenlands Bestuur, 2022; EBN, 2024). Furthermore, current legal frameworks make a distinction between the electricity sector and the heating sector, where the costs for the former are socialized while costs for heat networks are divided among connected users. *“In practice, this means that the costs are not divided across the whole country, but only across the end-consumers that are connected. This is contradictory to what is usual in the Netherlands.”* (R5). This has a stagnating effect on the energy transition and infrastructure integration, especially since individual heat solutions use a relative high amount of electricity (EBN, 2024). This becomes visible when congestion of the electricity grid complicates heat network development.

> This is an annoying showstopper, literally. It is very contradictory: we are developing collective heat networks with aquathermal energy to prevent grid congestion, but then the grid operator does not allow access to the grid. As a result, individual heat solutions are again stimulated. It is a vicious circle. (R5)

The stimulation of individual heat solutions is described by interview respondents as a consequence of the legal frameworks that are always a step behind on what is happening in practice: *"The bottleneck lies in the fact that legislation always lags behind what happens in practice."* (R4). To facilitate for the integration of water and energy infrastructures, the national government is currently working on new laws that will give municipalities more power in the development of sustainable heat solutions, like aquathermal energy-sourced heat networks. The Wcw (Law for collective heat) gives 51% ownership of collective heat systems to municipalities, where the Wgiw (Law for municipal instruments for the heat transition) gives municipalities the authority to decide when certain neighbourhoods are disconnected from gas, forcing the development of sustainable heat solutions (Binnenlands Bestuur, 2022). Next to that, the Dutch minister of Climate and Energy wants to introduce an emergency act in 2025 to reduce the costs for consumers of heat networks (De Volkskrant, 2024). The introduction of these laws will give transparency and trust in the price for the end-consumer compared to the current situation, where the price of heat from privately owned heat networks is less attractive and more prone to future price increases. It is noted that private heat suppliers are insufficiently triggered to keep their prices low in current frameworks (Nul20, 2024). The Wcw and Wgiw laws have been announced for multiple years already, but so far without approval. When they come into effect, it gives municipalities stronger instruments (and stakeholders a clear direction) in the energy transition. However, while not yet effective, the laws already have an impact on current transition planning as ownership and responsibilities become unclear, and investments are seen as risks. Currently, construction plans for sustainable heat networks are being cancelled in Amsterdam, as private companies are dealing with unsure business cases and ownership rights from their investments (De Volkskrant, 2024). This was also indicated during interviews:

> This really plays a role already. A lot of money needs to be put into the development, but maybe the investors won't be the infrastructure owners anymore. I see this in our project as well. The stakeholders are open to the development of heat networks and can collaborate with other parties to shape them. However, internally the thoughts are already with the new law: how will this be governed? These discussions are already being held. More clarity on this topic would really help. (R3)

Both currently and in case new laws are enforced, municipalities, while having the directing role, do still not have the final say in the development of heat sources in their area. Project developers have the obligation to implement sustainable alternatives for gas within their properties, and legal frameworks allow project developers to implement their own sustainable solutions (Pels Rijcken, 2022). This is also the case when municipalities have already assigned the neighbourhood in which their property is located as a collective heat network area. Where project developers look at solutions that are most economically beneficial in a case-based situation, these solutions do not always add most societal value:

> During a meeting with stakeholders in aquathermal energy, a project developer argued: it is nice that municipalities have been assigned the directing role, but in the end, it is us who make the final choice. We are looking at the lowest costs for our project. (R7)

While the integration of water and energy infrastructures is complicated by beforementioned institutional settings, the current phase is crucial for learning from successful aquathermal energy applications (STOWA, 2020) and for starting new (pilot) projects. Respondents from various sectors unanimously agree on the importance of starting projects to gain knowledge on the success or failure regarding aquathermal energy solutions. With current frameworks lagging behind, it is found that pilots and practice are needed in order to create suitable frameworks, and that governance arrangements will only fall in place after starting projects:

> It is a big puzzle with many pieces, and it is still unfinished. The pieces are solved one by one, and new pieces are still being discovered. The needed instruments are still to be completed and this needs to be done by gaining and keeping knowledge. (R2)

Explorative pilots can also help in supporting business cases that are often hard to realise. While their small scale does not have a significant impact on the energy transition, the experience gained from these can help prevent unexpected costs during projects, making costs more transparent and investments less uncertain.

> Pilot projects help here. They are small-scale, so they don’t make a significant impact for climate goals, but you still have to gain this experience to know what is good and what works or not. Without this, estimated costs can be twice as much in reality; pilots give you insights into implications that can prevent unpleasant surprises. (R9)

New insights from small-scale projects, however, will not directly lead to institutional changes. Still, stimulation for aquathermal energy projects is found to be needed from the national government, also to attract private parties for project executions and innovation:

> Without market parties, project development and innovation would come to a hold. However, they only come into action when there is sufficient demand, which can only be created by proper institutional encouragement. This is both needed, and this is a cause-effect relation. (R6)

While pilot projects are of importance, their progress is hampered by institutional barriers at the same time. Risks are present when investing in unknown areas, and no guarantee funds from higher institutional levels exist as a safety net to stimulate investments: *"You would need a guarantee fund that functions as a safety net. This could really help move things forward. The state could play an important role in this."* (R1). In addition, policy frameworks exist next to each other but are not aligned. When aquathermal energy exploitation is initiated, involvement of sectors like water, public space, and road management (each acting within their own policy area) makes for complex governing situations. When these domains are not aligned, aquathermal energy projects will get stuck somewhere along the process: *"An overarching policy for aquathermal energy in which all disciplines come together and in which this is being integrally organised, is absent. This is what we are mainly facing."* (R6). Furthermore, with many domains involved and unsuitable legal frameworks in place, requesting permits for aquathermal energy application can be a long and hefty process (STOWA, 2020). This is found as a demotivating barrier for infrastructure integration. *"Projects often get stuck once permits have to be given. You can wait years for this."* (R4). While this argument was recognized by other respondents, more perspective is given on the MRA as a region as it is also mentioned that these processes can be less complex. This is especially the case in smaller municipalities in which less people are active in each department, resulting in less division in priorities. However, while political decision-making is more effective, smaller municipalities may lack capacity in workforce and budget (Provincie Noord-Holland, 2022).

5.3.2. Actors and responsibilities

Next to provinces and municipalities, regional actors involved in aquathermal energy governance include waterboards, heat and energy suppliers (public and private), and housing corporations. Respectively, their sectoral responsibilities are achieving climate goals, managing water quality and quantity, building heat infrastructures, supplying heat from its source to end-consumers, and connecting housing units to a heat source. However, when these parties come together for aquathermal energy application, new roles are discovered, and it is yet unclear how these should be distributed. This can lead to friction in projects when stakeholders get involved in roles that were not assigned to them traditional and they are not knowledgeable about, are conflicting with their core responsibilities, or side-line another stakeholder. Moreover, stakeholders with equal responsibilities (such as waterboards) can take different approaches towards their involvement in aquathermal energy projects (passive/pro-active). Stakeholders recognize the need for collective involvement and integration; however, the division of responsibilities is currently unclear.

As was discussed before, municipalities have been assigned a directing role in the energy transition. The respondents involved from a municipal stance described their role as 'adopting policy in order to accelerate the heat transition'. They indicate the importance of municipalities taking responsibility to initiate a just transition. However, they are exploring questions regarding the exact role that municipalities should fill in, and every municipality is observed to interpret their role in their own way. Other stakeholders describe municipalities in the MRA as collaborating and facilitating partners, that do not necessarily initiate, but aim to jumpstart projects regarding aquathermal energy. Practice shows that stakeholders involved in the complex playing field of the energy transition are also searching for their roles, and while the role of municipalities should be leading (Energieregio NHZ, 2021a), stakeholders first look at each other when initiating projects, instead of at the municipality (Binnenlands Bestuur, 2021). This is exemplified by an aquathermal energy initiative in the city of Amsterdam, in which the waterboard, a housing corporation, and an energy infrastructure organisation had already initiated a project on aquathermal energy from wastewater, thus, taking over responsibility from the municipality. While initiatives are wanted, this causes the role of municipalities to remain unclear. *"On the one hand this is great, but on the other hand it should have been the municipality to stimulate such a project. In the end, such initiatives result in blurred responsibilities between the stakeholders."* (R3). This same pilot project on aquathermal energy has resulted in more interesting governance debates regarding the positioning and responsibilities of involved actors. From the three organisations that are collaborating (a housing corporation, a public water organisation, and an energy infrastructure organisation), only the latter are filling in responsibilities that are traditionally theirs as daughter organisation of a regional net operator. The housing corporation is responsible for affordable housing, but, while willing, no expert in sustainable heating solutions. The same can be said for the water organisation, which is responsible for the quality and quantity of water within its jurisdiction but not for energy supply. Yet, in reality it is more nuanced:

> The water organisation is a sewage company, but not a heat supplier. The energy organisation can legally operate the grid but is not allowed to supply heat. The housing corporation is allowed to arrange heat for a building, but exploiting heat supply does not suit in their core responsibilities either. (R9).

Furthermore, a difference in approaches followed by waterboards in the MRA was identified, while waterboards share the same responsibilities within their jurisdictions. Respondents involved in different regional waterboards both describe the involvement of their public water organisation as an important part of the energy transition. From their responsibility of source owners and managers of the quality and quantity of (waste)water, the potentials of aquathermal energy from their sources are strongly recognized. On the one hand, the approach to these potentials is described as 'pro-actively developing from their role as source manager'. This waterboard does not want to wait until requests regarding projects are received, and they instead are actively reaching out to stakeholders that can help in realising aquathermal energy potentials (HHNK, 2020). Conversely, while willing to support in projects, the second water organisation never initiates projects regarding aquathermal energy. This responsibility is given to stakeholders such as energy corporations and municipalities. *"We are responsible for managing water: this is what we offer. We see that there are opportunities, but we never take the initiative ourselves. We place this on other stakeholders, such as housing corporations, energy corporations and municipalities."* (R1). While having a different approach towards projects, both water organisations take in the same active position in mapping the potentials of aquathermal energy in their respective jurisdiction. It was indicated that they are mainly involved in the allocation of potentials and providing knowledge for municipalities, but water organisations can also take responsibility for the realisation of sewage systems suitable for aquathermal energy solutions (Waternet, 2024b). Next to regional waterboards, the national Department of Waterways and Public Works is involved in the development of aquathermal energy projects. Their role is to manage the quality of large waters holding much heat potential, for which it takes in a reactive position by issuing permits and facilitating knowledge developments between waterboards and municipalities to stimulate large-scale applications of aquathermal energy. It is recognized, however, that they are still searching for their role in the energy transition. While innovative thoughts are present, their implementation can be a slow process. *"You have to imagine us as a big containership going straight, and to deviate our course towards effective aquathermal energy applications can take years."* (R4).

Where the water sector is observed to have a different approach but shared responsibilities, the responsibilities of heat and energy organisations can differ. Where one organisation is responsible for the infrastructures that connect the heat source to end consumers but not for the extraction of heat from its source, others manage whole heat systems, from heat sources to the supply into buildings. Once they are contracted, they have the responsibility to deliver heat to customers. While holding the responsibility over the full heat chain, they do not recognize full responsibility for aquathermal energy infrastructures. The need for sectoral integration is being recognized, as aquathermal energy networks cannot be realised without the involvement of other actors. *"I don't think that there is a single private actor in the Netherlands that can deliver aquathermal energy from A to Z, as there are a lot of disciplines involved in the politics, infrastructures, electrotechnics, and engineering"* (R6).

5.3.3. Communication and coordination between stakeholders

The development of sustainable energy infrastructures, together with parallel developments in other domains, puts increasing pressure on the spatial dynamics, especially in densely populated areas like the MRA. Therefore, a solution lies in the integration of energy transition measures and infrastructures. This asks for effective coordination between stakeholders from different sectors. However, energy is still seen as a development in a single sector (Gebiedsontwikkeling, 2023). This is also noted by interview respondents. From a municipal perspective research collaborations with heat companies exist, in which the aim is to research which sustainable heat sources can supply heat networks in the future. However, project planning starts separately within sectors. Where in the electricity and drinking water sectors it is clear who takes the responsibility and future plans on these infrastructures can be coordinated, such interactions are not yet present where the water and energy sectors come together for the application of aquathermal energy:

> For such heat solutions, we just don't have a clear approach yet. This means that as municipality we could say that a neighbourhood will be connected to this, but a heat company will only execute when enough money is available. This complicates the coordination for infrastructure integration – you just can't make certain that a project will take place. (R9)

It is also mentioned that coordination between authorities for the development of integrated infrastructures is inefficient: ownership is often not in their hands because of concessions that were made in the past with big private companies for heat supply (R1 & R9).

Insights from the waterboards indicate, however, that there is active coordination taking place between themselves and the involved municipalities in the MRA. Waterboards are collectively researching potentials and effects of aquathermal energy use and aim to pass on this information to all municipalities. They emphasize that municipalities can consult with waterboards at any time regarding aquathermal energy. *"We try to speak to all municipalities within our jurisdiction. (...) When they have questions regarding the possibilities of aquathermal energy, they are not alone."* (R7). While this coordination exists between public organs, coordination with private actors is found more complicated. As investments need to be made for aquathermal energy systems, coordination needs to be concise to avoid the risk of sunk costs: when other private actors can deliver at a better price, the newly invested infrastructures will potentially remain unused (R7). This calls for a solution of city-wide coordination between policy, urban departments, and stakeholders, as was argued in a case study on Amsterdam, where coordination on energy transitions is currently only integrated into spatial development plans in a limited way (Gebiedsontwikkeling, 2023). Coordination in which authorities and sectors come together to decide on these factors is observed by interview respondents. *"We had multiple sessions in which the province, municipalities, the water sector, but also housing corporations, energy suppliers and network operators came together to coordinate who pays and who is responsible for what. All stakeholders want to make the energy transition a success."* (R4). The bottleneck in transforming these sessions into practice, however, is said to be in the organisation within the public-private discussion originating from the new heat laws that might be implemented in the near future (section 5.3.1). Next to that, when integration into existing heat infrastructures to supply aquathermal energy is wanted, private infrastructure owners demand high prices that are not feasible for these initiatives (R5).

Consequently, no new investments are made, and coordination does not take place. Therefore, coordination on infrastructure integration is found to work best between non-competing entities. This is currently successfully taking place in the MRA between citizen-initiated heat network co-operations.

> The co-operative projects meet each month and share what they are working on. We are not competing in any way – everyone has their own village and municipality. Everything is being shared, which is why co-operative movements are so effective. Market-liberalism does not stimulate processes in this phase, it only slows things down. Sharing knowledge is essential. We need transparency and openness! (R2)

However, since municipalities have mostly been working with commercial heat companies in the past decades, public co-operations are often also treated like commercial parties in current coordination. This creates friction between these actors, and municipalities need to learn how to coordinate with this new type of stakeholder.

Successful energy co-operations indicate the effect of motivated citizens and bottom-up coordination for the integration of water and energy infrastructures. However, one interview respondent indicates that coordination from municipalities only takes place with technical departments in the beginning of projects, while early involvement of social departments and co-operative initiatives are as important for project realisation, as is also indicated in the RES for the MRA (Energieregio NHZ, 2021b). Others also recognize the importance of this new type of stakeholder for the feeling of urgency among involved actors. To stimulate this, the waterboards organise yearly sessions to help municipalities in coordinating initiatives. However, there are found different insights on coordination between stakeholders regarding knowledge exchange on aquathermal energy. From a public-private energy company perspective, knowledge exchange infrastructures are in place and well-functioning. *"There are many different organisations that share their knowledge, to increase knowledge for application elsewhere. The infrastructure to get this knowledge to relevant parties is present, and this is flowing quite well."* (R5). Conversely, while actively accommodating knowledge exchange themselves, the perspective of a public water organisation is different: *"I think this happens too little – there is a national program to map lessons learned from projects on aquathermal energy, but I don't get the idea that this information is being shared sufficiently"* (R1), and *"A lot of knowledge exchange happened through NAT, a temporary national program for aquathermal energy. This doesn't exist anymore, and it is all very silent ever since. I don't expect a continuation of this."* (R7).

Sectoral values and interpreted outcomes of aquathermal energy projects are also found to influence the coordination between stakeholders. In line with regional strategies and other publications (Provincie Noord-Holland, 2022; Energieregio NHZ, 2021b; Gemeente Amsterdam, 2020; Binnenlandsbestuur,

2022) interview respondents indicate that collective heat networks are the most futureproof heat solutions, and stakeholders are seen to be open to coordination for cross-sectoral outcomes. While the need for integration is recognized, conflicting values stand in the way of actions taken by stakeholders. Municipalities want to proceed in an affordable and reliable manner and see private companies as important partners for implementation. However, a strong desire for transparency and trust is identified, which is not found in private companies that monopolise heat networks. *"Big private actors can't gain the trust of citizens. In Almere, citizens pay more for a connection to their heat network compared to a gas connection. They are complaining a lot about the obligatory connection to the network."* (Nul20, 2021). This is also an important consideration for housing corporations, which are an important connection for the feasibility of heat networks (Firan, 2021). Housing corporations have an underlying value to keep rent prices low for their tenants. Active coordination can fade, and they take in a passive attitude towards their connection to heat networks. Next to that, respondents argue that top-down coordination between institutions and private energy companies is too slow. Local aquathermal energy-sourced heat networks would be preferable. However, integration with city wide heat networks is often not seen as a solution, as upgrading aquathermal energy to a temperature suitable for a larger scale network uses too much electricity. Furthermore, conflicting sectoral outcomes can influence the coordination between water and energy sectors outcomes. Where the energy sector aims to develop infrastructures in the most efficient way, waterboards need to fulfil their legal responsibility of ensuring water quality, which is found in a pilot project in Amsterdam (VVplus, 2020):

> The waterboard said: we do not want this in our existing sewage system. We want to participate, but we will need to create a bypass from the existing sewage in which we can apply the heat switch. This way, we can ensure the fulfilment of our responsibility. (R3)

The involved stakeholders, however, have an understanding attitude towards each other's responsibilities, but these values can hinder infrastructure integration.

In the branch organisation of (private) heat companies, aquathermal energy is a much-discussed topic in which enthusiasm is seen among stakeholders. These, however, place the development within their own frameworks which are often conflicting, after which no further action is taken towards the coordination of further developments.

> We've had tours with waterboards, after which all kinds of representatives were very enthusiastic. A day later, everyone is hesitant as there are too many conflicting interests. That's why I think the national government should decide which interest is the most important. In this case, that would be the interest of achieving climate goals. (R6)

Finally, inefficient municipal project coordination is taking place when multiple sectors are involved. In a large-scale project for aquathermal energy application, the project execution could have been combined with new dike construction done by a different company. Sectoral outcomes were kept separately, and new permits had to be approved, resulting in a loss in time and money:

> These are examples in which it becomes visible that stakeholders are not fully open to integrate interests. This is making the application of aquathermal energy more and more difficult for us. We also see projects that we are not accepting, as we see big obstacles coming towards us through institutions or other parties, on which we have no influence. We can't take the risk to fail a project and not meet our responsibilities. In these cases, other solutions have to be found, while the potential for aquathermal energy in that area remains unused. (…) Project risks are too high and are not covered by the government. It is the big commercial parties that need to bring innovation: when the government is involved in everything innovation will never happen. (R6)

5.4. Spatial Context

Development and integration of water-energy infrastructures for aquathermal energy is seen as a complex task in the MRA, as involved stakeholders and governments act within different (sometimes overlapping) spatial jurisdictions. *"All these actors operate on different scales. In Amsterdam they are thinking on city level, while energy operators are active on regional level. Next to that there is the waterboard, again having a different spatial border."* (R9). The MRA is situated in two provinces, two energy regions, divided among four waterboards (Figure 7), 30 municipalities, and seven sub-regions (Figure 9). The Almere-Lelystad sub-region is least complex, being in the territory of two municipalities, one energy region and one waterboard. The remaining six sub-regions in the MRA are divided between one energy region that has six sub-regions, however, they do not share the same territories as the six sub-regions of the MRA (Figures 9 &10). Energy sub-regions consist of multiple municipal jurisdictions, except for Amsterdam and Haarlemmermeer. Furthermore, the six sub-regions are shared between three waterboards, and these three waterboards are all active in the city of Amsterdam alone. Waterboard Amstel, Gooi and Vecht has appointed Waternet as operating public water organisation, taking care of all water management tasks (drinking water, sewage, water management and purification) within the municipality of Amsterdam (with Heemstede, Amsterdamse Waterleidingduinen, and Schiphol being located in a different waterboard territory), and a division of tasks in the remaining waterboard territory (Figure 8). Additionally, within waterboard territories, larger waters (e.g. lake 'IJmeer' and river 'IJ') are managed by the national Department of Waterways and Public Works.

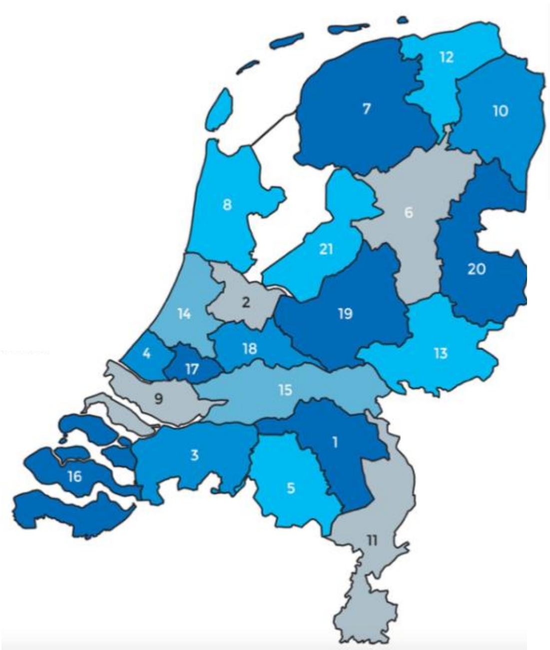

Figure 7: Waterboard territories in the Netherlands, with the MRA positioned within waterboards no. 2, 8, 14 & 21. Source: Openresearch.amsterdam (2023).

Figure 8: Waternet territory and tasks within waterboards Amstel, Gooi & Vecht and Hoogheemraadschap van Rijnland. Source: Waternet (2024c).

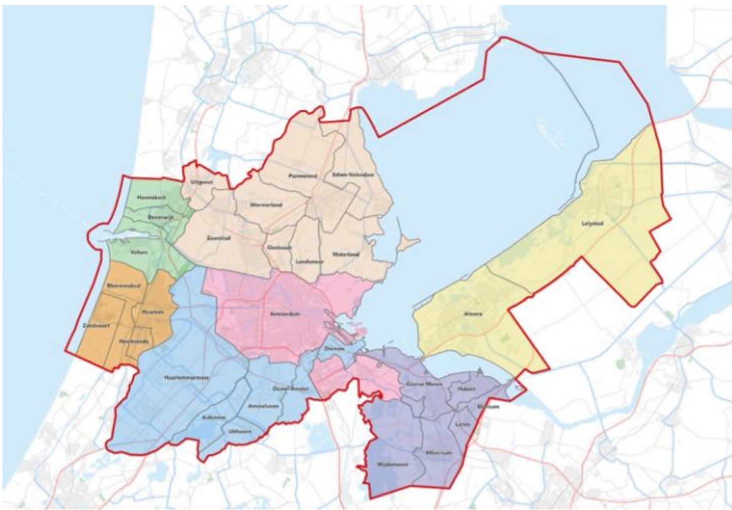

Figure 9: MRA territory, divided into seven sub-regions. Source: MRA (2024).

Sustainable energy sources are appointed on a (sub)regional level through so called 'searching areas' (Energieregio NHZ, 2021a). This results in different sustainable energy sources and different energy potentials per area that contribute to the total energy demand in the energy region of North-Holland South. These sources are then further developed on a municipal level. For the application of aquathermal energy, it is not found realistic to assign areas from a top-down level. These projects are highly case-specific, as there are too many considerations in play for their feasibility. *"If you organize this from a top-down, MRA level, it will go very wrong. You can assign sources and facilitate, but you need to learn how to stimulate a bottom-up approach."* (R2).

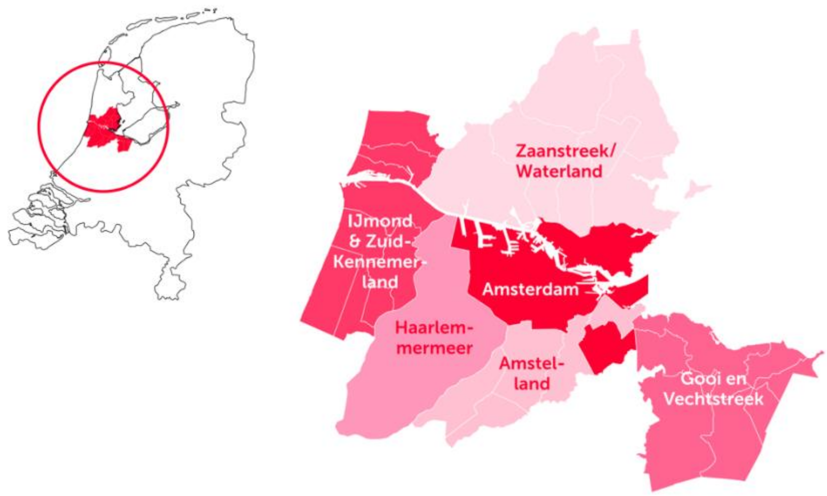

Figure 10: Division of energy region NHZ into six sub-regions, with white lines indicating municipal borders within sub-regions. Location in the Netherlands on the left. Source: Energieregio NHZ (2021b).

When looking at top-down optimalisation in the MRA, heat network integration is considered preferable. However, bottom-up networks that gradually grow towards each other are currently a more realistic way of looking at the integration between spatialities. For smaller municipalities this is especially a big challenge, as they have a relatively large territory with little inhabitants:

> From a technical point of view, I can imagine a top-down approach for what's optimal in the MRA. But we already find this to be difficult on the scale of Amsterdam, so more realistic is to work in a bottom-up way. Developing small networks that slowly grow towards each other, so integration takes place, and the robustness of the system increases. Even if we want to do it top-down, we don't have the right knowledge and frameworks for this. (R9)

While the knowledge and frameworks may not be there, the need for utilizing supra-municipal heat sources is stated in the Regional Energy Strategy (Energieregio NHZ, 2021b). Aquathermal energy is mentioned as a heat source holding potential for application on a regional scale, for example by connection to the privately managed heat network, located in and between Amsterdam and Almere (Image 2). Considering the spatialities in the MRA, this requires coordination between local and national (water) authorities together with a regional private energy corporation. To facilitate this multi-jurisdictional and cross-sectoral coordination, the Regional Energy Strategy proposes several committees that should bring together all public and private stakeholders that are involved (Energieregio NHZ, 2021b). In practice, however, these are not seen to be in place:

> Currently, there is no coordination between these territories. Laws are looking at better coordination and spatial arrangement, but too little is known to streamline these laws. (…) There is still so much heat available, that assigning this to an area now can result in huge blunders, when you later realize that you had rather used this heat elsewhere. Right now, we should accept sub-optimalisation. With the limited experience that we have, we cannot realise optimal solutions. (R9)

Territorial collaborations do occur between municipalities in the MRA when they are developing in a similar pace, but this remains a governance challenge. Moreover, in case heat sources can be used between municipalities, it is often the involved market party that initiates coordinating efforts, rather than the municipalities who have the directing role. *"Project organisations ask other municipalities if they are interested in the source, so it's not the municipal aldermen that are in contact about this. It's the market parties that arrange these things."* (R5).

In contrast, water authorities on different institutional levels communicate with each other in overlapping spatialities. Responsibilities can differ, and agreements have to be made between waterboards and the national Department of Waterways and Public Works. An interviewee mentions that there are no clear agreements on who is the leading authority in spatially overlapping projects, and coordination happens without standard protocol: *"The leading authority issues permits, while the other authority advices on which permits are needed. Sometimes it is confusing, but you shouldn't see it as demarcated areas and responsibilities. It's a very fluid process, and in the end, we need to do it together."* (R4). While this indicates active coordination, the coordination between these and other authorities is not always experienced as positive in development processes. The chairman of citizen-initiated heat network using thermal energy from surface water indicates viscous coordination between governmental spatialities. Many levels of government are involved in the arrangement of permits for underground aquifers or heat pump buildings. They all have their jurisdiction but are not familiar with their responsibilities, especially when issuing the permits needed for the extraction and transport of aquathermal energy:

> To build an aquifer for heat storage, the province is involved. For the heat pump building this is the municipality, but its placement area is owned by national real estate. However, they give responsibility back to the province. You're stuck in this viscous government, in which no one knows who needs to do what in these projects. (R2)

Furthermore, it is indicated that individual waterboards have more knowledge of aquathermal energy than the national water authority. *"I think this shouldn't be like this, and it results in an endless organization between territories. It shows how we are all going through a learning curve."* (R2).

Next to different spatialities that influence the coordination between authorities, different spatialities can also be identified within the city of Amsterdam. Multiple departments with unaligned interests operate here, and different interest may have priority. Next to that, large energy corporations that are active on a regional scale hold much power in deciding on the most suitable heat source within their territory. These factors make coordination between their spatialities and integration with (local) water infrastructures difficult. For the integration of water infrastructures with heat networks, an important consideration for location selections is the coordination between sectoral territories to create synergies by combining infrastructure developments: *"You need to know what is going on in all areas, so you can bring this together. This way, you create synergies."* (R2).

Based on the results in this chapter, the current fragmentation and coordination between water and energy sector action situations is displayed in the IAD framework as used for this research below (Figure 11). It visualises the institutional recognition of water and energy sector integration, which is vertically fragmented due to which horizontal coordination and outcomes do not fully utilize integration potentials between water and energy infrastructures.

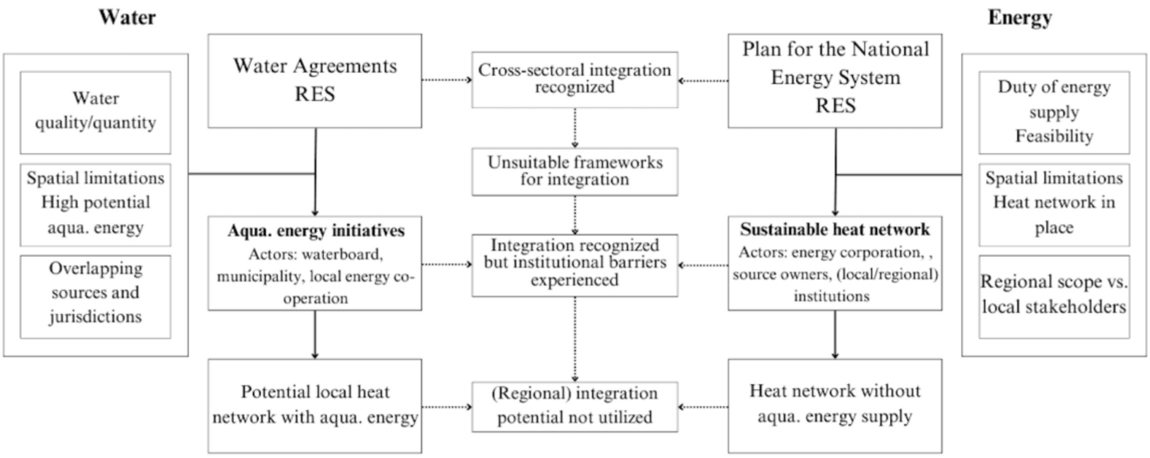

Figure 11: Institutional fragmentation and degree of integration based on research output. Own source.

6. Discussion

The main objective of this thesis was to explore the institutional fragmentation in governing aquathermal energy application in the Metropolitan Region of Amsterdam, by looking at the coordination between involved regional stakeholders, and how water and energy infrastructure integration is shaped by external variables. These four variables, derived from the theoretical framework (Chapter 3), included the physical and material conditions, the attributes of community, the rules-in-use, and the spatial context in the case study, which describe the action situation in which involved stakeholders coordinate. This framework has been applied to the research to answer the sub-questions supporting the central research question: "How can institutional fragmentation be addressed by stakeholders involved in aquathermal energy application in the Metropolitan Region of Amsterdam?".

This thesis expected to find a degree of institutional fragmentation on vertical, horizontal, and spatial levels. The empirical findings resulted in the identification of interconnected main themes supporting this expectation. Arguments that indicate the potentials of and willingness in aquathermal energy application on regional scale were found. However, barriers influencing aquathermal energy use on different scales have been identified, and desired regional scale application may not be realistic under current conditions. Furthermore, suggestions for addressing the institutional fragmentation were made, providing meaningful insights from different sectors.

This discussion section will continue by giving an overview and interpretation of the main research findings. It does so by addressing the three sub-research questions that support the answer to the central research question. It aims to find relations between findings and to relate these to existing literature and discuss their implications.

6.1. Observed responsibilities

This first section sets out the main findings under the current rules-in-use on the first sub-question of this research: *Who are the regional actors involved in aquathermal energy governance and what are their roles and responsibilities?*

The actors involved in aquathermal energy approach projects from their sectoral view of responsibilities. Their roles have evolved from individual sectors such as water management and energy supply. Findings of this research have shown how current responsibilities are not aligned for sectoral integration, and how this implies the complexity of implementing change in the energy transition in the MRA. When actors need to combine their responsibilities, new roles are being discovered and it is unclear how these should be distributed. While the role of initiation has been assigned to municipalities, different actors are seen to expect other stakeholders to fill in this role, leading to friction and blurred responsibilities between actors when cross-sectoral interdependencies appear. A cause for this can be described through the established institutional norms in the past decades where sectors and infrastructures developed separately, which was recognized by Monstadt and Coutard (2019) and was also found to be the case in the MRA where water is publicly managed, energy supply is mainly privatized, and policy frameworks exist next to each other. This relates to arguments made by Smith et al. (2005), who note that in socio-technical regimes, institutions have shaped the norms around infrastructures according to which the involved actors behave. While this may suggest that actors are stuck within their role, this research has revealed the willingness of different actors to take on extra responsibilities to realize aquathermal energy application. In the MRA, however, stakeholders are limited to their assigned responsibilities, with slow change as a consequence. This is in line with earlier studies by Hoppe and Miedema (2020), who showed that governance can be challenging in the absence of a formal leading actor, even when the willingness is there. Therefore, clarity in frameworks surrounding the division of new responsibilities is needed.

6.2. External variables shaping water and energy infrastructure integration

The following section focusses on the main insights into the external variables provided by the IAD framework regarding the second sub-question: *How do the physical conditions, rules-in-use, and spatial context of aquathermal energy shape the integration between water and energy infrastructures?*

In the MRA, the high potentials of aquathermal energy cannot be fully utilized under the current physical conditions that shape the integration between water and energy infrastructures. Regarding this external variable that was applied to the study, the main findings indicate that current infrastructures and spatial limitations are complicating the integration between infrastructures. In this research it was observed that (private) ownership of heat infrastructures forms an obstacle for integration, a finding that is supported by Osman (2017). In this case, it means that current infrastructures will likely not be used in combination with aquathermal energy. Consequently, a relation between infrastructure ownership and the utilization of aquathermal energy potentials can be observed. Where underground spatial limitations are a big challenge, existing infrastructures limit the possible locations for new infrastructures for the application of aquathermal energy usage. It may also be argued that, given the low temperature of aquathermal energy, new infrastructures need to be realized regardless. Still, areas with a heat network already in place are not perceived suitable for aquathermal energy application. This can further result in the uneven distribution of aquathermal energy use in the region, seen that only well insulated residences built from 1995 are suitable for low temperature heat networks.

Current rules-in-use do not provide the right instruments for the integration of water and energy infrastructures. Findings show fragmentation where national water and energy policies are combined with underdeveloped approaches, without an overarching policy bringing together the disciplines involved in aquathermal energy. Its governance is situated in a grey area for the regional scale, with data providing evidence of unsuitable frameworks and limited power for local institutions, caused by institutional mismatches on a higher level. These findings confirm earlier research by Heurkens and Dąbrowski (2020), in which they found that actions on one level impact the governance processes at other levels. This research adds to this, by finding that national financial regulations promote undesired developments on the regional level, hindering water and energy infrastructure integration. Furthermore, Lockwood and Devenish (2024) made a distinction between situations where institutions can be decentralized with major responsibilities for municipalities, while others are liberalized and privatized. This research gives new insights, as in the MRA both situations apply. This results in a fragmented state where friction exists between higher and lower institutional levels, due to the latter having limited capacities in filling in their assigned responsibilities, as well as state action having limited impact on infrastructure service provision. Within these socio-technical relations, Geels et al. (2017) call for a window of opportunity that is needed for regime change. The analysis of this research has identified upcoming energy laws as a possible window of opportunity, possibly taking away some of the current challenges for infrastructure integration upon their implementation. Finally, current research identifies a lack of focus on regional energy governance. While this is clearly also the case in the MRA and better regional governance is desired for the energy transition, this study implies that the current knowledge on aquathermal energy application is too limited to use a regional approach, and a more localized, bottom-up approach is required.

The spatial context in the MRA involving many jurisdictions complexifies the integration between water and energy infrastructures. It is found that municipalities individually appoint energy sources within their territory that lie within layered, partially overlapping water and energy (and institutional) territories. When supra-municipal aquathermal energy sources are available, municipalities have no ownership and utilization can be challenging. Where Goldthau (2014) advocates the analysis of such situations to better understand these governance mechanisms, this research answers that spatial fragmentation is problematic in aquathermal energy governance, especially since lower-level institutions have more knowledge on the subject than their overarching government organ. For integration between spatialities, regional energy operators need certainty for infrastructure investments from involved municipalities, which in turn are restricted in their power within national legal frameworks. This implies that this approach makes for a difficult playing field for regional energy operators that have the capacity to integrate supra-municipal sources. While this indicates the importance of including a territorial perspective (Walker, 2022), spatialities in the case study are in a starting phase regarding aquathermal energy application, making efficient integration between regional spatialities currently not always realistic.

6.3. Coordination within institutional and spatial settings

This third section discusses the interpretations and describes coordination within the action situation as shaped by external variables of the IAD framework regarding the third sub-question of this research: *How do regional stakeholders involved in aquathermal energy application coordinate their activities within current institutional and spatial settings?*

Within current institutional and spatial settings, coordination between institutions and the water and energy sectors were found. However, these are limited to an extent of knowledge exchange and do often not come to project realisations caused by conflicting attributes of community between involved stakeholders who act in different jurisdictions. The need for sectoral coordination is recognized in national policies, and regional energy strategies are created in collaboration with the energy and water sectors. Overarching organs to bring stakeholders together aim to be created, which clearly indicates the willingness for active coordination. Still, actors on the operational level do not experience these attempts, and a lock-in situation caused by silo planning in water and energy sectors is identified and a clear approach on the regional coordination between them lacks. At the same time, relations indicating a high degree of interdependency are found between sectors as legal frameworks force the energy sector to use sustainable energy sources, initiating the recognition of possible synergies. When coordination takes place, however, stakeholders are limited by institutional frameworks as integrative attempts are seen to lack (financial) support by the directing municipalities. Though, their capacity is hindered by different socio-technical factors, which is in line with research by Geels et al. (2017). They mention that current energy infrastructures can be more desirable, forming a barrier against niche developments. This is also the case in the MRA, and while long-term desirability is also recognized, infrastructure owners are not motivated to implement change as municipalities cannot provide attractive business cases.

Thus, this research presents relations between institutional mismatches and infrastructure ownership that are discouraging the coordination between water and energy sectors. Considering the coordination between spatialities in the MRA, this study has found similarities with research by Monstadt and Coutard (2019) and shows that the individual development of municipal jurisdictions lacks inter-municipal coordination, as these procedures and rules in policy domains and territories are not in place. Furthermore, when municipalities desire to make use of overlapping sources and infrastructures, energy companies involved in these territories are expected to take in a hesitant position based on the public-private discussion that aims to change legal frameworks. Conflicts are mainly found in the coordination between governments and private companies but do also exist between different departments within a municipality. It must also be recognized that coordination between the water sector and public actors and jurisdictions can be successful in the MRA, albeit on a small scale. In view of the literature review, in order to achieve active regional coordination, institutional frameworks would need to be considerate of socio-technical complexities and create incentives for stakeholders to integrate their activities, and responsibilities across spatial scales should be clarified and aligned (Moss & Hüesker, 2018).

7. Conclusion

This research has aimed to explore the fragmented institutional arrangements that govern aquathermal energy use in the Metropolitan Region of Amsterdam and how this shapes the integration of water and energy infrastructure for the involved regional stakeholders. It has done so by using external variables that have functioned to analyse and uncover different factors that influence the application of aquathermal energy within the current institutional settings, which had as aim to understand the action situation in which regional stakeholders operate and coordinate. After having discussed the research findings in the previous chapter, the main research question will now be answered, and suggestions will be made accordingly. Following, social and theoretical implications and recommendations for future research are given, after which research limitations will be addressed.

"How can institutional fragmentation be addressed by stakeholders involved in aquathermal energy application in the Metropolitan Region of Amsterdam?"

Research findings have revealed that utilizing the potentials of aquathermal energy in the case study context is an active topic among regional stakeholders, but faces barriers formed by a variety of external factors. Institutional fragmentation was found within underdeveloped national policies regarding aquathermal energy, that do not provide suitable frameworks for local governments and blur the responsibilities for important stakeholders, thus manifesting on multiple scales (Florentin, 2019). Considerations of the national government to improve regional governance through law adjustments result in new complications, which are amplified by physical and spatial complexities. Regional stakeholders experience no clear direction in the energy transition and call for stronger national level frameworks to be able to act and coordinate effectively. This is addressed through a need for clarity in responsibilities to steer stakeholders and to emphasize priorities. Transparency is wanted to stimulate the willingness for connection to aquathermal energy infrastructures for which the realisation is otherwise not feasible, and safety net funds are needed to make pilot projects possible. These can then further contribute to suitable, overarching, institutional frameworks. These suggestions, however, address fragmentation experienced in the start-up phase of aquathermal energy application. Bridging the gaps in institutional fragmentation on the metropolitan scale remains complex (Storper, 2014), and these interventions alone may not solve this. More experience must be gained, and socio-technical factors influencing infrastructure integration need to be further considered (Geels et al., 2017). This is currently only (limitedly) successful on a local level, bottom-up level. Therefore, regional application of aquathermal energy may not be realistic in the Metropolitan Region of Amsterdam in the short term.

This research has given new insights into the case study region, however, is still in line with previous literature which mentions energy transitions in metropolitan areas as complicated study objects. Although their nature was exploratory, the results may suggest that local governments should receive more power regarding water and energy infrastructure integration seen the complications that arise from private ownership. It also recognizes the importance of private actors for innovation and execution; thus, national frameworks should be put in place that not only limit their influence but also support their investments to stimulate progress. This could improve coordination with other sectors, making strides towards desired synergies. This study also proposes the continuation of past national programs on aquathermal energy through which knowledge was shared and financial support was given, as data indicates their effectiveness. While regional application may currently not be realistic, it is still seen as useful to create an overarching organ bringing together disciplines and spatialities in the MRA, as was mentioned in the Regional Energy Strategy. Doing so could enable better collaborations where possible and may help breaking through the institutional void over time (Monstadt & Schmidt, 2019).

Social and theoretical implications are identified as a result of this study. Staying with the case study area, the contributions of this research give direction in required changes to stimulate, accelerate, and realise gas-free alternatives in the energy transition. This can contribute to progress regarding climate agreement goals and assure that transitioning is feasible for both stakeholders and end-consumers, adding to societal value and equity. As the MRA is a frontrunner region in energy transitioning, the results are also relevant outside of the case study area. While external variables will never be the same, other regions can learn from and prevent barriers that were addressed, which could make for a relatively swift transition. This study is also found relevant for academics involved in the water-energy nexus and metropolitan governance, as it has given further understanding of the way in which institutions can influence coordination between involved actors. The applied framework has shown to be useful for finding relations between different variables that otherwise might have remained unnoticed, impacting governance between different sectors within institutional fragmentation. Adding the spatial context to this has provided useful insights into a sometimes-overlooked factor, which can be further applied to other studies.

Seen the focus on institutional fragmentation experienced from the perspective of the water and energy sectors, this research had a limited scope. From the collection of data from these sectors, it became apparent that sectors and stakeholders such as the housing and electricity sectors, but also citizens, are an important consideration for the study topic. Consequently, the results may not fully include relevant factors that could be provided by including a broader scope. Furthermore, time constraints did not allow for the analysis of all spatialities in the MRA, and the results might not be generalisable for the whole study area and the relationship between urban and rural areas. However, insights regarding these limitations were still obtained through the collected data from desk-research and experiences from interviewees who are involved with these stakeholders. Next to that, given that aquathermal energy is a specific topic with limited involved people in the region, certain specific scenarios and descriptions could not be fully provided, implying a difficulty in maintaining confidentiality.

Based on this, future research suggestions would include the focus on more diverse spatialities, with the aim to obtain more generalisable results for the region, allowing for detailed policy recommendations. Specifically, the inclusion of all relevant sectors and stakeholders is desired. It would be interesting to study how these perspectives can contribute to the observation of new relations and a better, or different, understanding of the fragmented institutional settings and the changes that are needed. Furthermore, where this study mentioned the future implementation of new laws giving stronger legal instruments to municipalities, it is recommended to repeat this case-study to analyse the effects after (and if) these laws are implemented. Consequent questions should focus on the new division of roles, how municipalities can operate collective heat solutions while most knowledge was developed in the private heat sector, how and if the private heat sector actively partakes in the energy transition, what the new laws will mean for energy prices, and if these laws will facilitate a transition away from fossil and individual solutions. Other research could focus on how an overarching policy on aquathermal energy could be developed, which could support in the integration of infrastructures within spatial limitations. Lastly, in the finishing stages of this research, it was noted that the Waternet organisation will be discontinued from the year 2025. As this is a relevant stakeholder in current frameworks, it seems crucial to study how its discontinuation impacts the governance dynamics in the region.

8. Reflection

The writing of this thesis has been a process of learning and adjusting. The essence of the methodological approach that was used, a combination of desk-research and expert interviews, has served as a good foundation to answer the research questions. However, the process of data collection and analysis could have been improved by following a more structured approach, distinguishing what is important for the topic and what effective ways to link results to theoretical frameworks are. Still, this research has managed to obtain relevant information from important stakeholders active in the case study area, who were successfully interviewed following the structure of the theoretical framework.

It has been hard to narrow down and obtain a clear focus regarding the execution of the research, which has been challenging. As the topic of study is highly complex, the researcher experienced difficulties in utilizing the proper literature and theoretical frameworks to support the study. This has resulted in multiple occasions of rewriting, researching, and possibly time-loss during the process. While difficulties were experienced in receiving responses to interview invitations, the relatively late data collection may also be related to the earlier research process. When frameworks were found, interpretations may sometimes have been unclear (and too complex) for feasibility, both regarding the researcher his experience and time constraints. It is recognized that this could have been prevented by maintaining a better structure and sometimes taking a reflective step back throughout the process, next to being more critical towards the own understanding and recognizing the need for supervisor involvement. Taking these factors into consideration, future research can result in a smoother process, improved results and be perceived as more reliable.

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10. Appendices

Appendix A – Interview guide Dutch

Voorstelronde en introductie van mijn onderzoek
Dit interview wordt gedaan als onderdeel van mijn afstudeerscriptie, welke wordt begeleid door Universiteit Utrecht. De informatie verkregen uit dit interview wordt gebruikt voor het beantwoorden van mijn onderzoeksvraag. Het doel van dit interview is om via experts nieuwe informatie te vergaren aan de hand van het theoretisch kader dat ik gebruik. Mijn interesse in dit onderwerp werd gewekt door het grote potentieel dat aquathermie theoretisch heeft in de MRA, in combinatie met onderzoeken waaruit blijkt dat de implementatie complex kan zijn. Ik focus in mijn onderzoek op de beleidskaders waarbinnen de water- en energiesectoren projecten uitvoeren, met name de coördinatie tussen deze partijen.

Vragen
Deze zijn opgesteld aan de hand van mijn theoretisch kader, zodat deze gebruikt kunnen worden voor analyse en resultaten.

Toestemming vragen om dit interview op te nemen en vergaarde informatie te verwerken en te gebruiken. Informeer interviewee over rechten, behandelwijze van data, en anonimiteit.

Actors
- Welke positie neemt uw organisatie in binnen de toepassing van aquathermie?
- Hoe ziet uw betrokkenheid hierbinnen eruit?

Attributes of Community
- Wanneer uw organisatie projecten uitvoert, wat zijn dan de belangrijkste waarden die leidend zijn voor de uitkomst van een project?
- Hoe past de uitvoering van aquathermie projecten hierin?
- Welke overwegingen zijn belangrijk in het besluitvormingsproces? (Bijv.: hoe wordt besloten welk project wordt uitgevoerd?)

Physical/Material conditions
Betreffende bestaande infrastructuur in de regio: kunnen deze worden gebruikt/herontworpen voor aquathermie, of zijn hier nieuwe infrastructuren voor vereist? Zijn er mogelijk technische uitdagingen bij, of spelen er misschien verzonken kosten die een belemmering kunnen vormen? Dus: (Hoe) kan aquathermie uit worden aangesloten op warmtenet (water/energie nexus)?

- Hoe wordt er omgegaan met land schaarste in de MRA in combinatie met de implementatie van aquathermie-infrastructuur (bijv.: bij de afstemming van ondergrondse infrastructuurprojecten)?

Interactions
- In hoeverre bent u afhankelijk van andere partijen/sectoren voor de implementatie van aquathermie? (Bijv.: is er behoefte aan coördinatie/integratie)
- Worden integratieve mogelijkheden (Bijv. water-energie-infrastructuur) erkend door de betrokken actoren?
- Hoe verhouden de belangen en doelstellingen zich tussen u en betrokken partijen? Zijn er conflicten en zijn er goede voorbeelden van samenwerking? (Bijv.: houding van netbeheerders tegenover aquathermie integratie)
- Hoe beïnvloeden conflicterende doelstellingen de coördinatie met andere sectoren?

- Wat belemmert op dit moment de samenwerking met andere sectoren?

Rules-in-Use

- Welke beleidskaders zijn er momenteel die de uitvoering van aquathermie projecten ondersteunen of belemmeren?
- Is er ruimte voor flexibiliteit binnen deze kaders voor projecten? (Bijv.: welke acties kunt u (niet) ondernemen?)

Aangezien formele besluitvorming op nationaal, provinciaal en gemeentelijk niveau wordt gedaan, en de MRA een regio zonder formele overheid is:

- Welke rol spelen de provincies en gemeenten in het ondersteunen van aquathermie projecten?
- Gemeenten moeten de regie voeren, maar hoe wordt dit tussen hen gecoördineerd in de MRA? (MRA gas-vrij, maar niet elke gemeente heeft zelfde agenda, budget, bronnen – wat zijn de incentives/verhoudingen voor ontwikkeling?)

Gezien de complexiteit van verschillende sectorale en overheidsgebieden (territories) in de MRA:

- Hoe worden infrastructuur en projecten gecoördineerd binnen de (overlappende) gebieden? (Bijv.: hoe gebruik maken tussen territories, met meerdere jurisdicties van waterschappen/sectoren/overheden)
- In hoeverre zijn verantwoordelijkheden en doelstellingen tussen sectoren en territories op elkaar afgestemd?

Kunt u samenvatten op welke manieren de huidige beleidskaders barrières of kansen in uw sector voor de implementatie van aquathermie?

Results

- Welke/hoeveel aquathermie projecten zijn er in uitvoering? Waar ziet u de kansen en knelpunten in die projecten? (Bijv: Is er een feedback/lessons learned mogelijkheid met de belanghebbenden en autoriteiten?
- Kunt u aangeven hoe de huidige coördinatie/samenwerking tussen partijen/sectoren in aquathermie projecten eruitziet? (Bijv: waar zijn de kansen/knelpunten?)
- Wat is er nodig om meer gebruik te maken van de potenties van aquathermie, in het kader van een gas-vrije MRA? (Bijv: wat voor verandering is er nodig: beleidsverandering, betere samenwerkingen, subsidies)

- Heeft u nog aanvullingen die van belang zijn voor dit onderzoek?
- Zijn er personen werkzaam op dit gebied die ik absoluut moet interviewen?

Appendix B – Interview guide English

Introduction and Presentation of My Research

This interview is conducted as part of my graduation thesis, supervised by Utrecht University. The information obtained from this interview will be used to answer my research question. The goal of this interview is to gather new information from experts based on the theoretical framework I am using. My interest in this topic was sparked by the great potential that aquathermy theoretically has in the MRA, combined with studies showing that implementation can be complex. My research focuses on the policy frameworks within which the water and energy sectors execute projects, especially the coordination between these parties.

Questions
These are formulated based on my theoretical framework so that they can be used for analysis and results.

Request permission to record this interview and process and use the gathered information. Inform the interviewee about rights, data handling, and anonymity.

Actors

- What position does your organization take within the application of aquathermy?
- What does your involvement in this look like?

Attributes of Community

- When your organization executes projects, what are the key values guiding the outcome of a project?
- How does the execution of aquathermy projects fit into this?
- What considerations are important in the decision-making process? (E.g.: how is it decided which project is executed?)

Physical/Material Conditions

Regarding the existing infrastructure in the region: can these be used/redesigned for aquathermy, or is new infrastructure required? Are there potential technical challenges, or perhaps sunk costs that might form a barrier? So: (How) can aquathermy be connected to the heat network (water/energy nexus)?

- How is land scarcity in the MRA handled in combination with the implementation of aquathermy infrastructure (E.g.: in the alignment of underground infrastructure projects)?

Interactions

- To what extent do you depend on other parties/sectors for the application of aquathermy? (E.g.: is there a need for coordination/integration?)
- Are integrative possibilities (e.g.: water-energy infrastructure) recognized by the involved actors?
- How do the interests and objectives relate between you and the involved parties? Are there conflicts and are there good examples of collaboration? (E.g.: the attitude of grid operators towards aquathermy integration)

- How do conflicting objectives affect coordination with other sectors?
- What currently hinders collaboration with other sectors?

Rules-in-Use

- What policy frameworks currently support or hinder the execution of aquathermy projects?
- Is there room for flexibility within these frameworks for projects? (For example, what actions can you (not) take?)

Since formal decision-making is done at national, provincial, and municipal levels, and the MRA is a region without formal government:

- What role do the provinces and municipalities play in supporting aquathermy projects?
- Municipalities have the directing role, but how is this coordinated between them in the MRA? (MRA gas-free, but not every municipality has the same agenda, budget, resources - what are the incentives/divisions for development?)

Given the complexity of different sectoral and governmental areas (territories) in the MRA:

- How are infrastructure and projects coordinated within the (overlapping) areas? (E.g.: how to make use of territories, with multiple jurisdictions of water boards/sectors/governments)
- To what extent are responsibilities and objectives aligned between sectors and territories?

Can you summarize the ways in which the current policy frameworks create barriers or opportunities in your sector for the implementation of aquathermy?

Results

- Which/how many aquathermy projects are in progress? Where do you see the opportunities and bottlenecks in these projects? (E.g.: is there a feedback/lessons learned possibility with the stakeholders and authorities?)
- Can you indicate what the current coordination/collaboration between parties/sectors in aquathermy projects looks like? (For example, where are the opportunities/bottlenecks?)
- What is needed to make more use of the potentials of aquathermy, in the context of a gas-free MRA? (For example, what change is needed: policy change, better collaborations, subsidies)

- Do you have any additional comments that are important for this research?
- Are there people working in this field that I absolutely must interview?

Appendix C – Coding scheme

External variable	Code
Physical and Material conditions	Sources and locations
	Current water infrastructures
	Current energy/heat infrastructures
	Spatial limitations
	Location selection
Rules-in-Use	Policies and (legal) regulations
	Actors and responsibilities
	Vertical coordination
	Horizontal coordination
	Knowledge exchange
	Business cases
Attributes of Community	Leading values
	Sectoral interpretation of outcomes
	Risks and incentives for integration
Spatial context	Institutional spatialities
	Sectoral spatialitites
	Spatial overlap
	Coordination between spatialities