Master's thesis – Master Sustainable Business and Innovation

Accelerating development of Dutch thermal energy cooperatives

Practices from Denmark and Germany to resolve systemic barriers in the Dutch context

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Abstract

The *Introduction* discusses the importance of transitioning towards a low-carbon heating system. Thermal energy cooperatives that develop district heating systems are identified as a socio-technical innovation system with high potential to increase public acceptance. This research aims to aid the development of thermal energy cooperatives in the Netherlands through resolving systemic problems, by identifying successful practices in Denmark and Germany.

The *Theory* expands on the characteristics of district heating systems and examines current literature on (thermal) energy cooperatives. The theoretical framework on 'Systemic barriers' is proposed, which can identify problems that hamper the development of innovation systems. Finally, the institutional contexts of the Netherlands, Denmark, and Germany are described.

The *Methods* section describes the qualitative research design. 10 case studies were conducted, of which four in the Netherlands, four in Denmark, and two in Germany. The data collection includes documents and 17 semi-structured interviews. Also, the method for data analysis is explained.

The *Results* present the practices from Denmark and Germany to overcome the identified systemic barriers in the Netherlands. Multiple systemic barriers were identified, and thermal energy cooperatives are found to be strongly influenced by the environment in which they develop

The *Discussion* compares the findings of this research with findings from other scientific studies and found that studying energy cooperatives from a socio-technical perspective is useful. Also, limitations are given in relation to recommendations for future research.

The *Conclusion* gives recommendations to policymakers, municipalities, public banks, and cooperative organizations. The following practices were found in Denmark and Germany and are recommended for application in the Netherlands:

1. Low-interest and long-term loans from public banks with municipalities as guarantee were found to be highly favorable in Denmark and Germany. Those will support Dutch cooperatives to improve the business case and be realized.
2. Standardized heating contracts and cost-based pricing could overcome regulatory barriers, improve trust of consumers towards district heating and increase transparency in the heating sector.
3. Thermal energy cooperatives should lobby collectively at the national government to establish favoring regulations and increase legitimacy. Workshops and lectures should be aimed at governmental organizations to increase awareness.
4. Municipalities should take cooperative district heating initiatives seriously and provide them with collaboration, support, and subsidies.
5. To increase professionality within thermal energy cooperatives, Energie Samen or other cooperative organizations can support on administrative, financial, and technical aspects. Such cooperative organizations could operate multiple cooperative district heating systems themselves.

List of abbreviations

Abbreviation	*Explanation*
ACM	Authority for Consumer and Market
ATES	Aquifer Thermal Energy Storage
CHP	Combined Heat and Power
DH	District Heating
HP	Heat Pump
KfW	German development bank (in German ‘Kreditanstalt für Wiederaufbau’)
NG	Natural Gas
PAW	Program Natural-gas free Neighborhoods
PTES	Pit Thermal Energy Storage
REC	Renewable Energy Cooperative
TEC	Thermal Energy Cooperative
TTES	Tank Thermal Energy Storage

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1. Introduction

1.1. Context

Climate change calls for transformations of energy systems worldwide towards a sustainable and carbon-neutral society (Kooij et al., 2018). Urban areas are responsible for a significant part of the global energy use and associated greenhouse gas emissions, with heating being households' main final energy consumption (Lampropoulos et al., 2020). Transitioning to a low-carbon heating system, which is also known as the heat transition, is key to decrease the dependency on fossil fuels. The heat transition is both a technical and a social transformation, requiring co-creation with citizens, industry, national, and local governments (Caramizaru, & Uihlein, 2020; Lampropoulos et al., 2020).

The Netherlands aims to phase out natural gas (NG) in the built environment by 2050, as agreed within the Climate Accord (EZK, 2019). Municipalities have the "directing role" in this transition and must execute heat planning per neighborhood, for which they can follow three main strategies: collective, individual, and in-between configurations (EZK, 2019; Herreras Martínez et al., 2022). Collective systems refer to district heating (DH) systems, while individual systems involve individual heat pumps (HP). This study focusses on the DH systems for neighborhoods.

DH systems provide thermal energy to a network of buildings, including residential, commercial, and industrial users (Rezaie, & Rosen, 2012). Those systems ensure a secure heat supply and relieve customers of maintenance, fuel supply and operations, while the multiple energy sources, including renewable ones, can be combined, and connected (Mazhar et al., 2018; Schmidt et al., 2017). Operators of DH systems have a natural monopoly within the system's area of supply, as customers cannot purchase heating from other companies (Gorroño-Albizu, & de Godoy, 2021; Roth et al., 2022; Sunko et al., 2017). This negatively affects affordability and freedom of choice. Moreover, substantial conversion is required of both homes and streets (Warmtecoalitie, 2020). Therefore, construction and connection of DH systems can only take place if citizens and municipalities agree.

This is where energy cooperatives provide an interesting opportunity (Wierling et al., 2018). Energy cooperatives can be perceived as a social enterprise that strives for economic, social, and cultural advancements of its members by following goals other than profit maximization (Yildiz et al., 2015). Historically, they have enabled social innovations, empowered communities, and even influenced the local and EU-level energy field regulations (Bauwens et al., 2022). Energy cooperatives bring more significant economic benefits to the local community than commercial projects due to the use of local labor and materials and yield financial benefits to the local community (Hicks, & Ison, 2011). Energy cooperatives also allow for democratization of access to capital and such cooperatives therefore help to increase social acceptance (Capellán-Pérez et al., 2018; Schumacher et al., 2019).

1.2. Problem definition

In the existing literature on energy cooperatives, difference can be made between renewable energy cooperatives (REC) and thermal energy cooperatives (TEC). This study focusses on TECs, which can be regarded as a form of energy cooperatives but with a focus on the provision of thermal energy to a community of actors in a local area (Fouladvand, et al., 2022). A TEC can be defined as "*an initiative, governed by citizens, focused on developing a cooperative heating supply source, where the residents have authority and/or ownership to a certain extent*" (TNO, & Energie Samen Buurtwarmte, 2021). TECs are likely to differ from RECs in institutional and social factors, due to major technological differences between electricity and thermal energy (Fouladvand et al., 2022). The electricity sector, for example, is highly competitive on an international market as individual producers can supply electricity to the grid, while DH is a locally bound heating supply (Roth et al., 2022).

Most attention has been paid to RECs as a sub-category of energy cooperatives, while TECs has been studied less in the existing literature. Regarding studies focused on TECs, the technical component has been studied the most (Fouladvand et al., 2022). Such topics include energy system design, demand-side management, and thermal storage. The second component is stakeholders, where the division of financial responsibilities, the influence of leadership, and the roles of different stakeholders on local acceptance have been studied (Fouladvand et al., 2022). The third component refers to institutions, where regulatory design, market design and pricing strategies have received academic attention.

Kooij et al. (2018) found that the development of energy cooperatives is strongly influenced by the environment in which they will develop. Also, TECs are entangled with a wide range of external actors and institutions and are dependent on the political and physical infrastructure. Furthermore, the heat transition involves the transition of one socio-technical system to another socio-technical system, which is where difficulties are for sure to arise that hamper the transition (Geels, 2005; Negro et al., 2012). These are referred to as systemic problems, which are defined as *"all systemic factors that block the operation and development of innovation systems"* (Negro et al., 2012). Mignon and Rüdinger (2016) researched the impact of systemic problems on RECs and found that institutional contexts impact their development.

In the Netherlands, the number of TEC initiatives has increased from 9 in 2016 to 78 in 2021 (HIER, & RVO, 2022). Of those projects, only two are operational, and four have started construction. There are disparities in the number of TEC between countries. Deployment of TECs has succeeded at the most significant scale in Denmark, with around 310 operating TECs (DEA, 2017; Mazhar et al., 2018). There, they are referred to as "heat cooperatives". Other TECs can be found in Germany, where they are most often referred to as "bio-energy villages". The number of TECs in Germany, however, is unknown.

1.3. Aim and research questions

The aim of this study is to identify the systemic problems that Dutch TECs encounter and find suitable solutions through researching the institutional context and case studies in Denmark and Germany. Denmark and Germany were chosen for their 1) high rate of successful TECs, 2) cooperative history, and 3) existence of a large literature body. The following main research question was drafted:

What best practices from Denmark and Germany can be applied to overcome the systemic problems that Dutch thermal energy cooperatives have encountered?

For answering the main research question, three sub-questions were formulated:

RQ1: What systemic problems do Dutch thermal energy cooperatives encounter?

RQ2: How did Danish and German thermal energy cooperatives encounter the main systemic problems that were found in the Netherlands?

RQ3: What practices allowed Danish and German thermal energy cooperatives to mitigate and/or overcome the main systemic problems?

By answering these questions, this study contributes to existing literature by researching TECs in Denmark, Germany, and the Netherlands from a socio-technical perspective. Therefore, this research takes a more holistic approach than previous studies on TECs. Moreover, it adds by using the theoretical framework on systemic problems by Mignon and Rüdinger (2016) for application to TECs. This has not been done before. The societal contribution is to research how the identified systemic barriers can be overcome by applying successful practices from other countries. By overcoming those barriers, development of TECs and thus the heat transition can be accelerated.

The research is organized as follows. First, the theory is explained, including a description of the institutional context of the Netherlands, Denmark and Germany. Then, the theoretical framework is presented. Second, the methodology is described, along with descriptions of the research design, data collection, and data analysis. Then, the results are presented. This section is divided into three parts, each focused on one sub-question. Finally, the main findings are discussed in relation to existing literature, and the limitations and recommendations for future research are given.

2. Theory

The theory section first provides a description of DH systems within the literature, after which the definition and characteristics of TECs are given. Then, a description of the institutional contexts in the Netherlands, Denmark, and Germany is given. Finally, the relation to innovation literature is made and the theoretical framework is presented, along with descriptions of the systemic problems.

2.1. District Heating systems

2.1.1. Technical system

Collective systems are referring to DH systems that provide thermal energy to a network of buildings, including residential, commercial, and industrial users (Rezaie, & Rosen, 2012). DH systems consist of three main interdependent parts: the heat sources, the heat distribution network, and the connected buildings. The heat is distributed in the form of hot water or low-pressure steam through an underground insulated piping system (Rezaie, & Rosen, 2012). The DH network can also function as a district cooling network when necessary (Mazhar et al., 2018). DH systems can provide efficiency, and environmental and economic benefits to communities and customers such as a secure heating supply. Customers are also relieved of maintenance, fuel supply, and operations (Schmidt et al., 2017).

Another benefit of the DH system is the flexibility regarding the energy source, as multiple energy sources can be combined and connected (Mazhar et al., 2018). Renewable and waste heat sources are the most preferable, as this allows for decarbonization of the heating system. Especially low-temperature DH (below 90 degrees Celsius) provides opportunities, as that allows for efficiently utilizing renewable energy (Mazhar et al., 2018; Schmidt et al., 2017). However, low-temperature DH, often requires sufficient building insulation levels and thus adjustments to buildings. The following heat sources are commonly used in DH systems:

- Combined Heat and Power (CHP) plants that produce both electricity and heat, which can operate on a variety of fuels such as biogas, biomass, NG, and oil.
- Waste heat from industrial processes and datacenters. Only the waste heat from processes depending on renewable energy are regarded as renewable.
- Geothermal heat is a renewable source found deep within the Earth's surface for which large investments are required due to drilling and equipment.
- Waste incineration is already used in large-scale DH systems and provides huge potentials in European urban centers. Its challenges are related to clean combustion and efficient waste management systems.
- Solar thermal: can be developed on small to medium scale and can be both centralized and decentralized. Challenges are that solar energy is unpredictable as a source and not reliable without large-scale thermal storage. The potential lies mostly on small-scale decentralized setups.
- Aquathermia is a renewable source that refers to thermal energy from water. There are three sources for aquathermia: from surface water (TEO in Dutch), from drinking water (TED in Dutch), and from wastewater (TEA in Dutch) (NAT, n.d.).

The sensible heat is extracted in the summer months, stored, and heated in the winter with water HPs. There are three different storage possibilities:

- Aquifer thermal energy storage (ATES) stores heat in the subsurface.
- Pit thermal energy storage (PTES) stores heat in an artificial pool.
- Tank thermal energy storage (TTES) stores heat in an insulated tank.

2.1.2. Business case

Significant upfront investments are required for constructing the DH system (Sunko et al., 2017). The most important investments are construction of the heat production facility and distribution network, which are also the most significant (DEA, 2015; Sunko et al., 2017; TKI Urban Energy, & RVO, 2020; TNO, & Energie Samen Buurtwarmte, 2021). Other investments are related to the transmission network, transmission stations, and building connections (TKI Urban Energy & RVO, 2020). Buildings often need to be adjusted by including a heat exchanger and additional insulation before connecting to a DH system. Those investments, however, are handled separately from the business case.

The largest challenge in developing DH systems is the "off-take risk", which occurs when less people than projected connect to the DH system (TKI Urban Energy, & RVO, 2020). It is important to start with a secure revenue flow as the investments upfront are significant (Sunko et al., 2017). Moreover, the size of the DH system can be scaled in such a way that the demand meets the initial base load, while still having opportunities for grid extension. Support within the community is necessary to achieve a high connection rate and therefore reduce the "off-take risk".

There are three methods to finance DH systems: equity, loans, and grants. Equity capital represents the personal investment of the owners of the project and can come from existing earnings (Sunko et al., 2017). Also, employees, private investors, and venture capital firms may provide equity. Equity from private investors and venture capital firms is often translated into ownership. Also, crowdfunding from (future) customers is a common method of funding cooperatives. Connection fees can also be regarded as equity capital, which heating companies can charge to all new customers for connecting to the DH system (Sunko et al., 2017; TKI Urban Energy, & RVO, 2020).

Loans can be obtained from banks, who become the creditors and suppliers of debt in return for an interest rate (Sunko et al., 2017). Loans vary by repayment schemes and interest rates. The time period may vary between 3 and 30 years or more. The interest rate depends on the institution, loan terms, and perceived financial risk by the creditor. Public institutions often pursue lower interest rates and longer payback times than private institutions, as they are not pursuing significant returns on their investments (Sunko et al., 2017). In addition, governments can guarantee a loan, which makes the guarantor liable for a portion or all the debt (TKI Urban Energy, & RVO, 2020). In general, that lowers the interest rate of loans.

Subsidies can be granted by governmental organizations, including municipalities, provinces, and the national government (Sunko et al., 2017; TKI Urban Energy, & RVO, 2020). The majority of the funding come from grants, as it reduces the investment cost and thus enables a competitive heating price (Sunko et al., 2017). Two types of subsidies can be identified: investment and exploitation subsidies (TKI Urban Energy & RVO, 2020). Investment subsidies are meant to finance part of the investment and are always bound to the European rules on state aid. Exploitation subsidies are meant for the exploitation phase of the project to cover the unprofitable peak and are given for a fixed amount of time.

Heat companies can charge a wide range of costs to consumers. However, to protect consumers against the monopoly position of DH systems, governments are often regulating the heating prices (Roth et al., 2022). Different price mechanisms can be distinguished within Europe. Below an overview of the potential costs that heat companies can charge is given:

- Connection fee for connecting the building to the DH system.
- A contribution for the heat exchanger.
- Fixed costs per year and fixed costs per kW.
- Variable costs per kW.
- Metering rate per year for metering the heating and/or cooling usage.
- Operational costs for running the DH system, which are significantly lower than the investment costs. That is mainly due to energy-efficient heat production facilities such as residual heat or CHP plants (TKI Urban Energy & RVO, 2020).

2.2. Energy Cooperatives

Energy cooperatives are a specific purpose-oriented legal form of renewable energy communities, that often emerge *for* communities (Bauwens et al., 2022). The field of activities of most energy cooperatives concentrate around its operating region (Wierling et al., 2018). Energy cooperatives can be perceived as a social and economic enterprise that strives for economic, social, and cultural advancements of its members by following goals other than profit maximization (Yildiz et al., 2015). As there is little literature on TECs, the rest of this section focusses on the existing literature of energy cooperatives. When this paper refers to energy cooperatives, those can be focused on renewable energy, thermal energy, or both. This means that when this paper refers to RECs, only energy cooperatives with renewable energy projects are meant.

Energy cooperatives promote collective citizen action to address various aspects of the transition to a low-carbon energy sector such as energy savings and renewable energy projects (Bauwens et al., 2022; Fouladvand, Ghorbani, et al., 2022). The cooperatives engage the wider public decision-making processes through ownership and enabling them to acquire shares (Caramizaru & Uihlein, 2020; Klein & Coffey, 2016; Knoefel et al., 2018). The generation of profits is often limited as that is not the goal, and surpluses can be reinvested to support the local community or the members of the cooperative (Caramizaru & Uihlein, 2020).

People joining energy cooperatives usually have heterogenous motivations (Bauwens, 2016). Therefore, one energy cooperative may contain different investor profiles. The variation between these diverse motivations could be explained by the importance given to material aspects and community aspects. Environmental objectives are the most mentioned within literature (Bauwens et al., 2022). Other studies, however, have shown that priority is often given over environmental drivers to social drivers for acting in the interests of the community, such as local income generation, community empowerment (e.g., knowledge generation and increasing expertise), and community cohesiveness (Bauwens et al., 2022; Brummer, 2018; Hicks & Ison, 2018; van der Schoor & Scholtens, 2014). Achieving renewable energy production is often seen as a means to the end of improving social coherence within the community (van der Schoor & Scholtens, 2019).

Political drivers playing a role in motivating citizens to join community projects were found to be a community's desire for autonomy, stable energy prices, and independency from governments and corporations, as has been observed in Denmark, Scotland, and Spain (Bomberg & McEwen, 2012; Heras-Saizarbitoria et al., 2018; Johansen & Werner, 2022). Ambitions related to energy efficiency, heat supply stability, energy equity and sustainability have been found for district heating projects in Denmark (Johansen & Werner, 2022).

2.2.1. Thermal energy cooperatives

Development of DH systems by TECs is different compared to the development of DH systems by commercial companies, because TECs are often inexperienced, lack expertise, and lack financial capital (TNO & Energie Samen Buurtwarmte, 2021). Within the development of TECs in the Netherlands four phases can be distinguished, which are shown in Figure 1 (TNO, & Energie Samen Buurtwarmte, 2021). Each phase consists of three steps, and the aim is to increase the trust of all involved parties with each step.

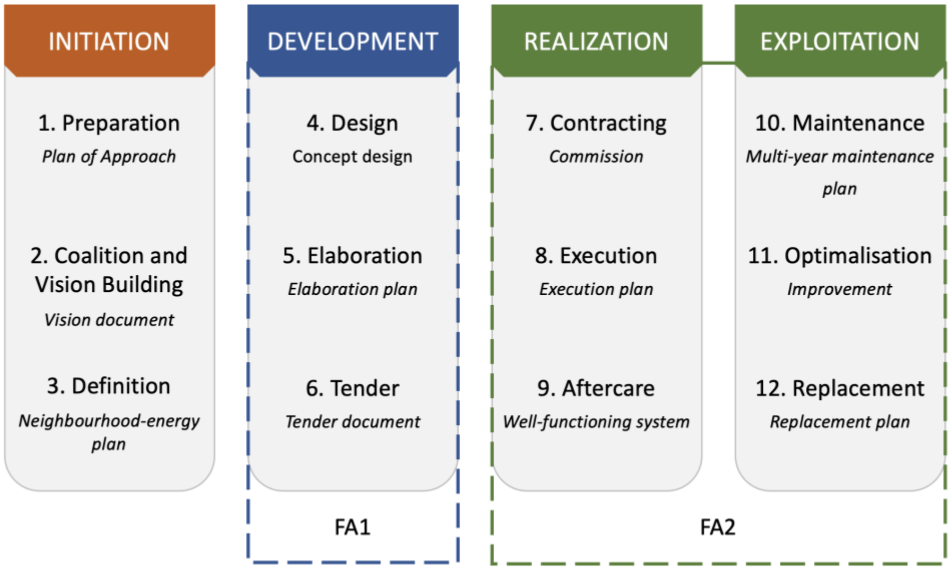

Figure 1. Four phases for development of TECs in the Netherlands, adapted from TNO and Energie Samen Buurtwarmte (2021).

The goal of the *Initiation* phase is to investigate whether district heating in the neighborhood is feasible, meaning that the neighborhood is investigated including the insulation levels of buildings and potential heat sources. Additionally, citizens will start becoming engaged and support needs to be acquired. The result of the initiation phase is a plan containing an initial business case, with a techno-economic assessment of heat sources and potential demand, and a first exploration of financial options. Within the initiation phase, the initiatives are commonly dependent on high number of invested hours by volunteers, and subsidies can be obtained from the municipality or province. The neighborhood-energy plan at the end provides the start for the next phase *Development*.

Within the *Development* phase the business case is finalized, and financial close must be reached by obtaining financing. Many activities will be executed within this phase, including designing the technical system, signing start contracts with residents, acquiring permits, and formulating tenders for construction. Financial capital must be attracted to bear the higher risks of this phase. Often this involves capital at different times and from multiple parties. Those parties can be commercial companies in return for ownership, or municipalities providing subsidies. At the end of this phase, financial close must be reached, meaning that the DH system can be realized.

Within *Realization and exploitation,* the DH system is finalized and will be exploited. Here, funding must be obtained from financial institutions before being realized. Therefore, TECs must proof that they meet the assessment criteria of those financial institutions. When the system is realized, the TEC will generate income where expenses must balance income.

2.3. Institutional contexts

This section gives an overview of the institutional contexts of the Netherlands, Denmark, and Germany respectively.

2.3.1. The Netherlands

In the Netherlands, 5.9 percent of all dwellings were connected to a DH network in 2019 (CBS, & TNO, 2020). The ACM distinguishes two types of DH networks: large-scale and small-scale. Large-scale networks supply yearly more than 0,15 PJ heating, while small-scale supply less than 0,15 PJ (CBS, & TNO, 2020). There were 19 large-scale networks in 2018, supplying 329.000 connections in total. These networks are owned by the following 5 commercial companies: Eneco, Ennatuurlijk, HVC, SVP, and Vattenfall. The majority of dwellings connected to large-scale networks were new constructed buildings (CBS, & TNO, 2020).

Small-scale networks supplied 2,4 PJ in total in 2018 to 64.000 connections (CBS, & TNO, 2020). Small-scale networks are not monitored by the ACM, due to their large diversity. The number of those networks is estimated to be between 100 and 200, supplying around 64.000 connections in total. The majority of those networks are based on NG-CHPs (37.300 connections) and ground-coupled heat exchangers (14.300 connections). Only one of those networks is cooperatively owned: Culemborg supplies 220 households.

The Dutch DH market is regulated by the Heat Law that was established in 2014 and was last updated in March 2022 (Rijksoverheid, 2022). The law only applies to connections lower than 100 kilowatts, and the aim is to protect consumers against the monopoly position of DH suppliers. The Dutch Consumer and Market Authority (in Dutch 'ACM') is responsible for monitoring the market and regulating the heat prices.

The ACM determines the maximum prices for heating consumption, heat exchangers, metering, connection, and disconnections (ACM, 2020). The consumption prices are coupled to the natural gas prices in accordance with the "Not More Than Others" principle (in Dutch 'Niet Meer Dan Anders') to protect consumers (TKI Urban Energy, 2020). This means that the heat tariffs of the average DH consumer may not surpass the heat tariffs of the average natural gas consumer. The ACM investigates yearly if the financial returns can be considered reasonable. Aim of this monitor is to evaluate the Heat law and if adjustments are necessary.

Since October 2021 the ACM acquired the ability to further regulate financial returns. They can determine whether an individual heat supplier achieves higher than reasonable returns, and when they do, the ACM can decrease the heat tariffs of that heat supplier in the next year. However, what the definition of reasonable returns still needs to be determined, for which the ACM needs higher transparency of the heat suppliers' activities. Transparency around costs and accountancy, however, is low due to the lack of standards and large variety of heating companies.

The only entry rule for heating companies is that they must have a heat supply permit. This is only applicable for heating companies that supply more than 10 customers and more than 10.000 gigajoules per year (ACM, 2019). The permit must be obtained from the ACM, which evaluates the company beforehand on three dimensions: technical, financial, and organizational.

The supplier is obliged to inform the heat consumer in a transparent way on multiple matters such as the description of the supplied district heating; level of the heat tariff; clarity on possibilities of interim contract termination; and information of customer service. In addition, the supplier is bound to rules around billing (ACM, 2020). The bill, for example, must be clear and understandable, and must be send within six weeks. In case of a system malfunction that leads to an interruption of the heat supply of more than eight hours, the heat supplier must financially compensate the heat consumer. The level of compensation is determined by the ACM and differs per length of the error.

The only legal form for heating companies is the private limited company with legal personality, also known as 'BV' in Dutch (Rijksoverheid, n.d.). Within that legal form, the company's equity is divided into shares owned by shareholders, while the directors run the daily activities. Shareholders have the authority to appoint and fire directors; approve annual accounts and budget; decide profit destination; determine policy; modify articles of association and regulations; and sell the company. Four possible ownership options can be distinguished for TECs: 100% cooperatively owned; co-ownership of the municipality, co-ownership of a commercial company, and co-ownership of both the municipality and a commercial company (Notten, 2020). In case of a co-ownership, the statutes of the heating company always determine majority of ownership for the cooperative.

The Dutch government is in the process of updating the Heat Law, towards the so-called Law Collective Heating (EZK, 2022). This will be further referred to within the report as Heat law 2. A concept version was published in June 2020, although it is currently in consultation and expected to enter into force in July 2024. The focus here is on the aspects that are most important for the deployment of TECs. The Heat law 2 proposed that municipalities can appoint a heating company to an area that will be responsible for producing, distributing, and supplying DH to the customers in that area (Energie Samen, 2020). The municipalities may decide those areas for DH networks, and their sizes. Smaller systems within those heating areas will not be allowed if they affect the business case of the appointed heating company within that area. An exception is likely to be included for systems up to 1.500 WEQs (EZK, 2022). In addition, possibilities for total public ownership of DH infrastructure by municipalities and local network operators are being investigated. Another proposed reform is decoupling DH prices from NG-prices and switch towards cost-based heat prices. Furthermore, the ACM is drafting regulations around accountancy, to increase transparency in the DH market (EZK, 2022).

2.3.2. Denmark

In Denmark, around 64% of all houses is supplied by DH systems (DEA, 2017). Other heating sources include individual boilers running on NG, oil, or biomass, and individual HPs. Due to the high energy efficiency and large potential of DH systems to include renewable energy, the Danish government set the goal to convert 50% of all NG-heated houses to DH systems or individual HPs by 2028 (The Local, 2022).

The heating system in Denmark has benefitted from a long-term stable energy policy, historical events, and a nationally supported local heat planning framework (Chittum, & Østergaard, 2014). The DH sector is regulated by the Heat Supply Act, for DH systems more than 250 kW and CHP units up to 25 MW, while larger CHP plants are regulated by the electricity law (DEA, 2017). DH companies are overseen by the Danish Energy Regulatory

Authority and the Board of Appeal, which also handle complaints regarding prices and conditions.

The Heat Supply Act disallows Danish heating companies to make profits as to protect the customers. If profits are made, this must be returned to the customers via decreased heat prices in subsequent years (Chittum, & Østergaard, 2014). Furthermore, transparency regarding heating prices and technical metrics is obligatory, while heating companies can be benchmarked on the total heating costs on a voluntary basis (Wiegerinck, n.d.). This protects customers against inefficient management, and allows customers to monitor whether the heating costs are based on the necessary expenses, and object when that is not the case (DEA, 2017).

Heat planning in Denmark is highly decentralized. Municipalities are the single responsible entities for local heat planning and approval of heat companies' activities and projects (Chittum & Østergaard, 2014). They have been since the first heating supply law, which was introduced in 1979 (DEA, 2017). Then, municipal heat planning was divided into three steps. First, municipalities had to map the existing heat demand, future heat demand, existing supply method, future supply methods, and the existing amounts of energy used. Second, municipalities prepared options for future heat supply methods. Third, the regional heat plans were prepared, which identified the priority of heat supply options in an area (also called "zoning"). The possible heat options for zoning were NG and DH systems. Zoning is based on the socioeconomic costs based on a pre-established methodology by the DEA. Cities have the freedom to develop the most cost-effective projects for their citizens (Chittum, & Østergaard, 2014). The municipality even had the right to oblige existing and new buildings to connect to DH if that heat source was appointed by the municipality to have the lowest social costs in that area. Building owners were obliged to pay the connection fees and annual fees to the heating company, whether they used DH or not. The obligatory connection regulation was abolished in 2019 as to reintroduce "freedom of choice". Furthermore, municipalities have the ability to collect information that is essential for their local heat planning tasks from any heat company, while they can also require heat companies to undertake specific projects under specific timelines (Chittum & Østergaard, 2014).

Danish heating companies are almost always controlled by consumers, directly or indirectly (Chittum, & Østergaard, 2014). There are three main ownership models for DH: municipal ownership, cooperative ownership, and private ownership (Johansen and Werner, 2022). Currently there are 49 municipally owned DH companies, which supplied around 60% of sold heating from DH in 2019. Those are typically based in urban areas. The 323 cooperatively owned DH companies supplied approximately 34% of sold heating in 2019, which are primarily based in rural areas and small towns. The private ownership types supplied around 7% in 2019, and typically exists when a CHP plant is owned by a commercial party and the heating must be sold.

Danish heating companies are often controlled, directly or indirectly by municipal agencies and councils (Chittum & Østergaard, 2014). When heating companies are fully cooperatively owned and controlled, municipalities are still on their board of directors and are empowered to approve heat projects. This enables municipalities to directly influence the daily operations and long-term strategic plans of heating companies (Chittum & Østergaard, 2014).

2.3.3. Germany

Individual gas and oil boilers are the most used heat carrier in Germany. DH systems are the third most used heat carrier and supplied around 14% of dwellings in Germany in 2012 by 560 DH suppliers (Wissner, 2014). The type of ownership is heterogeneous, but the majority of DH systems are supplied and operated by municipalities (Mazhar et al., 2018). The German DH sector is still dominated by fossil fuels, and mainly dependent on CHPs (Triebs et al., 2021).

The DH sector in Germany is not regulated at the national level and is significantly less regulated than the German electricity market (Triebs et al., 2021). The sector is, however, affected by different laws from the energy sector, such as the Cogeneration Act, Renewable Energy Act, Renewable Heat Act, and the Ordinance on energy savings (Aumaitre et al., 2018). Germany has set the goal to be climate neutral by 2045 and the switch to renewable energies in the heating sector is a priority (Wettengel, 2022). By 2024, new heating systems must operate on 65% renewable energies if possible.

There are no rules around transparency for bookkeeping and about technical and financial factors, while transparency on those factors is mandatory within the German electricity market (Pelda et al., 2021). The conditions regarding heat delivery are often contractually agreed upon between the concerning parties, and difficult to research. Therefore, deriving general statements about technical key metrics is nearly impossible in Germany, also because every DH system is unique with their own characteristics.

The German Renewable energy act is the nation-wide legal framework and the most important policy instrument for the promotion of renewable energy in Germany (Roesler & Hassler, 2019). The Renewable energy act regulates the feed-in compensation for electricity that is produced by renewable energy. Biogas plants only convert 40% of total energy into electricity, while 60% remains unused as residual heat. To be more energy efficient, biogas plant operators are incentivized by the Renewable energy act to use a certain amount of residual heat. When they do so, operators receive a higher compensation for the electricity they feed into the grid. Therefore, farmers are often offering residual heat for minimal compensations or for free to local communities, so they obtain higher feed-in compensation.

The German Renewable heat act is the national framework for heat production based on renewable energy sources, and important for financial aspects of implementing and running a bioenergy village (Roesler, & Hassler, 2019). The market incentive program 'Marktanreizprogramm' is part of the Renewable heat act and supports heat supply networks with financial credits from the German development bank (KfW).

2.4. Systemic problems in technical innovation systems

TECs are entangled with a wide range of external actors and institutions, operate within and across scales, and are dependent on the political system and physical infrastructure (Creamer et al., 2018; Fouladvand et al., 2022). The speed, direction, and success of EC are strongly influenced by the environment in which they develop (Kooij et al., 2018; Mignon, & Rüdinger, 2016; Warbroek et al., 2019). This corresponds with the literature on technical innovation systems (TIS), that interprets innovations as outcomes of interactions between dependent consumers, producers, research and education, the political system, the supply system, and the physical infrastructure (Hufen, & Koppenjan, 2015).

Innovation systems typically involve the transition of a socio-technical system to another socio-technical system (Geels, 2005). This transition is not a smooth and efficient process, and takes time (Negro et al., 2012). Within this process difficulties arise that hamper the development and diffusion of innovation systems. These are referred to as systemic problems, which are defined as *"all systemic factors that block the operation and development of innovation systems"* (Negro et al., 2012). For speeding up the transition, the systemic problems hampering the diffusion require additional attention from policy makers and other system actors. Therefore, it is crucial to have adequate understanding of the potential barriers at the different system levels.

Negro et al. (2012) studied the impact of systemic problems on renewable energy technologies by analyzing 50 case studies related to renewable energy technologies. They concluded that systemic problems hamper the development and diffusion of such technologies. Negro et al. (2012) proposed a typology for systemic problems, and stress that the systemic problems are not independent but interact with each other.

The typology was adapted by Mignon and Rüdinger (2016), for application on identifying systemic problems that impact the development of REC projects. They have found that systemic problems have impact on two levels: they may impact renewable energy projects for all new entrants, and they may impact REC projects specifically. For better applicability on TECs, the grid infrastructure was renamed to 'Physical infrastructure'. The categorization of the systemic barriers by Mignon and Rüdinger (2016) is the theoretical framework of this research and can be found in Table 1. The framework is explained further below.

Table 1: Categorization of the systemic problems, as identified by Negro et al. (2012) and adapted later by Mignon and Rüdinger (2016) for identifying systemic barriers for cooperative renewable energy projects.

Theme		*Definition*
Market structure		The organization of the current market
Hard institutions	For DH	Formal rules within the institutional context affecting DH systems
	For TECs	Formal rules within the institutional context affecting cooperatives
Soft institutions		Social norms and values, culture, and perceived legitimacy
Financial infrastructure		Present structures for acquiring financial capital
Physical infrastructure		Present technical structures
Knowledge and interactions		Knowledge and interactions with all system actors

2.4.1. *Market structure*

The market structure can be defined as the current organization of the market in which a system is embedded. For grassroots initiatives it is important to have favorable entry rules and a level playing field (Kooij et al., 2018). In Denmark, for example, the small-scale entrepreneurial oriented economy and decentralized energy system were found to be favorable for energy cooperatives, as those are decentral by nature (Kooij et al., 2018). Other factors to compete within the heating market may differ per institutional and biophysical context (Kooij et al., 2018). For example, high NG-prices may strengthen the business case of other heating technologies such as individual HPs and DH systems.

2.4.2. *Hard institutions*

Within the innovation systems theory the institutional context is seen as a defining and structuring element in the system (Mignon & Rüdinger, 2016). Hard institutions refer to the formal rules within the institutional context, such as existing and future laws, regulations, legal forms, and required permits.

An unstable regulatory framework leads to uncertainties and may hinder the development of energy cooperatives (Hewitt et al., 2019; Wierling et al., 2018). Supportive regulatory frameworks in the past, with for example feed-in tariffs and tax incentives, have shown correlation with growth of energy cooperatives (Hewitt et al., 2019; Wierling et al., 2018). Many REC projects, however, have been developed without the existence of such arrangements in Sweden and Spain among other countries. Those suggest that the existence of supportive policy schemes is not always essential (Guerreiro & Botetzagias, 2018; Hewitt et al., 2019; Kooij et al., 2018; Young & Brans, 2017).

Furthermore, misalignment between policy levels, different sectors, and existing and new institutions may be a systemic problem. For example, local governments may strongly stimulate projects from energy cooperatives, while regulations from the national government may hinder the development (Negro et al., 2012).

2.4.3. *Soft institutions*

Soft institutions refer to the social norms and values, culture and legitimacy that may hinder the development of TECs. Legitimacy is about social acceptance within the society and local community for new technologies and the cooperative model (Mignon & Rüdinger, 2016; Negro et al., 2012). Legitimacy is formed through conscious actions by organizations and individuals, including cognitive, normative, and regulative aspects (Bergek et al., 2008). New technologies can be de-legitimized by actors through, e.g., their performance, potential, and proven functionality.

2.4.4. Financial infrastructure

The financial infrastructure focusses on the present structures for energy cooperatives to acquire financing (Mignon & Rüdinger, 2016). They are associated with the availability of financing (e.g., subsidies or loans) from the national and regional governments, and the ability to acquire financing (e.g., investments or loans) from other actors such as private banks and commercial companies. The lack of financing in the development phase by governments may be detrimental for new technologies, as they hamper their possibility to overcome the high-risk phase (Mignon & Rüdinger, 2016).

2.4.5. Physical infrastructure

Physical infrastructure refers to the technical structures required for the innovation to function. They play a huge role in the transformation of the heating infrastructure based on NG towards DH and are associated with large investment costs and coordination problems. The biophysical characteristics of the area affect the DH systems in different ways, for example regarding the delivery temperature and heat loss (Sunko et al., 2017). Also, the local availability of renewable energy sources (e.g., biomass or residual heat in the vicinity) significantly influences the selection of the heating source.

2.4.6. Knowledge and interactions

Knowledge and interactions refer in general to the availability and functioning of a knowledge infrastructure (Mignon & Rüdinger, 2016). Negro et al. (2012) also refers to knowledge infrastructure as the availability of knowledge that is required for a socio-technical transition, which can be the result of interactions. Therefore, knowledge and interactions are divided into two aspects. First, knowledge refers to the knowledge present among system actors, which can affect deployment of an innovation. This includes the capabilities of system actors, for example their knowledge on technology and financial models, and their communication skills.

Second, interactions involve the types of relationships with all actors that are related to the project or have a stake in the project. Interactions between stakeholders are necessary to diffuse knowledge. The following stakeholders can be found for development of TECs: building owners, housing associations, water authority, consultancies, local community, and the municipality (TKI Urban Energy, & RVO, 2020). Too strong or too weak interactions may lead to systemic problems. For example, as found for renewable energy projects: if interactions between utilities are too strong, they may be reluctant to accept new entrants and they would thus try to influence policymakers in restricting their emergence (Negro et al., 2012). Too weak interactions, however, may lead to missed opportunities.

3. Methods

This section describes the used methods for conducting the research to answer the main research question. First, the research design is described. Then, the methods for data collection are explained, along with an explanation on case study selection. Also, an overview of the cases is presented. Finally, the data analysis is described, followed by a note on ethics.

3.1. Research design

To answer the main research question, it is important to understand the real-world examples of TECs and their relation to contextual conditions. As TECs differ largely in their characteristics, this research is based on a multiple-case study design, featuring ten European cases. The evidence found in multiple-case studies is often considered more compelling, robust, and reliable than a single-case study (Yin, 2014). This research is divided into three phases, as shown in Figure 2. During each phase, an iterative process was followed where data was collected and analyzed almost simultaneously.

The purpose of Phase I is to identify the systemic barriers that TECs in the Netherlands have experienced between February 2022 to July 2022. This was done along the theoretical framework by Mignon and Rüdinger (2016). Therefore, the institutional context of the Netherlands was analyzed through desk research and interviews. Furthermore, four case studies were performed. During Phase I, five systemic barriers were identified, which formed the basis of Phase II.

Phase II aims to identify whether established TECs in Denmark and Germany encountered the same systemic barriers as the Netherlands, and if so, what practices were adopted to overcome them. Only the identified systemic barriers in the Netherlands, as found within Phase I, have been researched in Denmark and Germany. To understand the institutional contexts of both countries, desk research and interviews were performed. Subsequently, a total of six case studies were conducted, of which four in Denmark and two in Germany.

Phase III aims to examine whether the practices found in Phase II can be applied in the Netherlands. This is done through comparing the identified practices from Denmark and Germany with applicability in the Netherlands. Therefore, desk research and interviews were conducted.

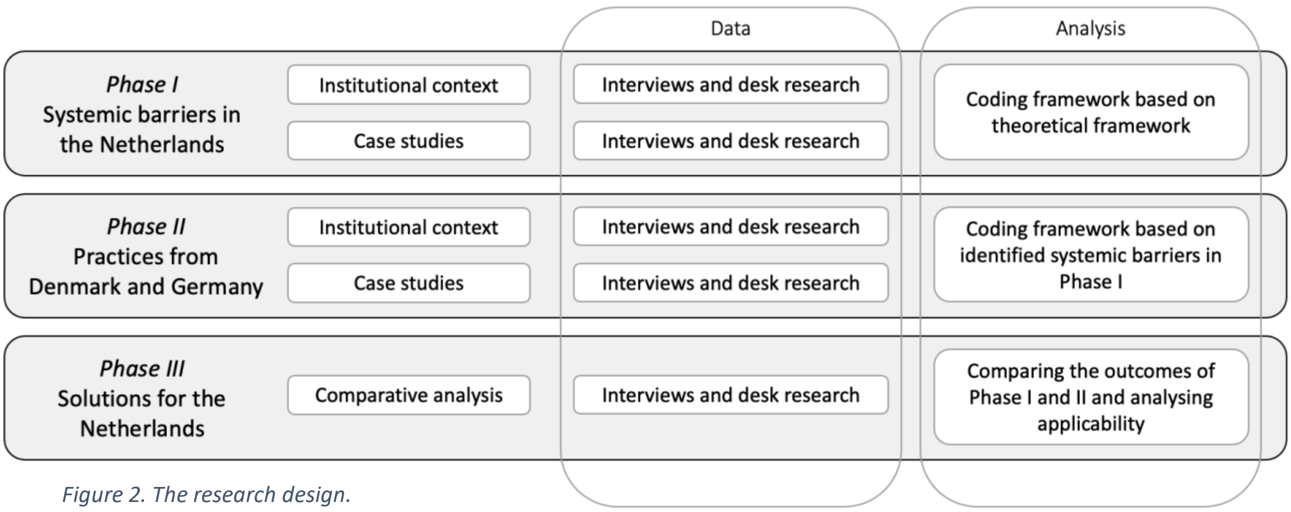

Figure 2. The research design.

3.2. Data collection

This research is based on data collected from different sources. Those include scientific literature, grey documents, and semi-structured interviews. First, the data collection for understanding the institutional contexts is explained. Then, the methods for case studies are described including the sampling strategy.

3.2.1. Institutional contexts

For analyzing the institutional contexts of Denmark, Germany and the Netherlands, desk research was conducted. This includes both scientific and grey documents. Scopus is used for collecting scientific documents. An overview of the used search queries for scientific literature can be found in Table 2. Grey documents include government documents, policy documents, research reports, and news articles. Those were collected through Google searches and examining the websites of relevant actors. In addition, some documents were recommended by interviewees.

In addition, eight expert interviews have been conducted for understanding the country contexts, of which five for the Netherlands and three for Denmark. The interviewees were identified as experts within their knowledge field and found through Google searches or snowballing. Snowballing refers to recruiting interviewees through referrals from individuals who share a particular characteristic (Bryman, 2012). Interviewees were approached via telephone, e-mail, or LinkedIn. An overview of all interviewees shown in Table 3.

All interviews within this research have been semi-structured. The semi-structured approach allows collection of data on attitudes, perceptions, and understandings (Bryman, 2012). Interviews were conducted online through MS Teams and lasted longer than one hour. Every interview was recorded and transcribed afterwards, to decrease possibility of misunderstanding and misinterpretation (Cho & Trent, 2006). This increases validity of the findings.

Two standardized interview guides were developed, as to increase the structure of the interview and replicability, and thus enhance cross-case comparability (Bryman, 2012). The interview guide of Phase I was only used for the Netherlands and was based on the theoretical framework of Mignon and Rüdinger (2016). The guide of Phase II was based on the identified systemic barriers of Phase I. The interview guides can be found in Appendix A.

Table 2. Overview on the used keywords for finding scientific literature in Scopus.

Subject	*Search queries*
Thermal energy cooperatives	("heat*" OR "thermal") AND ("energy community" OR "energy cooperative" OR "energy initiative") OR "bioenergy village"
District heating regulations	“district heat*” AND (“regulat*” OR "institut*") AND (“Netherlands” OR “Denmark” OR “Germany”)

Table 3. Overview of all interviewees

Code	Position	Purpose	Phase	Country	Month
INT-01	Professor energy regulation	Context	I	The Netherlands	May '22
INT-02	Director "Buurtwarmte" at Energie Samen	Context	I	The Netherlands	May '22
INT-03	Initiator Ketelhuis	Case	I	The Netherlands	June '22
INT-04	Senior thermal energy consultant	Context	I	The Netherlands	June '22
INT-05	Lead energy cooperatives at municipality Ketelhuis	Case	I	The Netherlands	June '22
INT-06	Initiator Panningen	Case	I	The Netherlands	June '22
INT-07	Initiator Muiderberg	Case	I	The Netherlands	July '22
INT-08	Initiator Duinwijck	Case	I	The Netherlands	July '22
INT-09	Director at Energie Samen	Context	I	The Netherlands	August '22
INT-10	Specialist district heating and energy transition at the public bank of Dutch municipalities	Context	I	The Netherlands	August '22
INT-11	Director Lemvig	Case	II	Denmark	June '22
INT-12	Director Bjerringbrø	Case	II	Denmark	June '22
INT-13	Director Viborg	Case	II	Denmark	July '22
INT-14	Director Aalborg	Context	II	Denmark	July '22
INT-15	Director Hammel	Case	II	Denmark	August '22
INT-16	Legal consultant at Dansk Fjernvarme	Context	II	Denmark	July '22
INT-17	Head of development at Dansk Fjernvarme	Context	II	Denmark	July '22

3.2.2. Case studies

In total, ten case studies were performed: four in the Netherlands, four in Denmark, and two in Germany. The case studies and participants were selected through purposive sampling, as to acquire information from experienced individuals or organizations (Devers & Frankel, 2000). Selection of the case studies was based on two criteria: the heating company must have cooperative ownership, and the main customers must be households. Especially the latter criteria ensures that the findings are comparable to Dutch TECs as all Dutch TECs are mainly focused on providing heating to households. Furthermore, the researcher has made an effort to select cases with a diverse range of used technologies within the DH system within each country. An overview of the cases can be found in Table 4.

For collecting the data of the case studies, nine case interviews were conducted with initiators or directors of TECs (see Table 3). These interviewees were approached by telephone, e-mail, or LinkedIn, and some cases were approached via snowballing. Case Ketelhuis is the only case for which two interviews were performed.

The data collection of the German context was done in a different way than that of the Netherlands and Denmark, as finding interviewees in that country has been highly difficult. The main problems were the language barrier between the researcher and potential interviewees and the time availability of potential interviewees. Therefore, the two German cases have been researched solely through desk research, which includes reports, news articles, and e-mail correspondence.

Table 4. Overview of the case studies in the Netherlands, Denmark, and Germany.

	Ketelhuis	*Panningen*	*Muiderberg*	*Duinwijck*
Municipality, and location	Amsterdam, within WG-neighborhood	Peel en Maas, in the town of Panningen	Gooise Meren, in the town of Muiderberg	Vlieland, within neighborhood Duinwijck
Status per 06-2022	Development	Development	Development and Realization	Realization
Start year initiative	2018	2018	2020	2016
Expected realization	2024	2023	2024	2022
Connection ambition	3.000 WEQs ambition	4.779 WEQs ambition	1.200 households ambition	40 connection ambition, but 39 realized
End-users	Households and non-residential buildings	Households and non-residential buildings	Households and non-residential buildings	38 Households and 2 utility buildings
Primary source	Aqua thermal from surface water, industrial HPs, ATES	Solar thermal on land, industrial HPs, residual heat, TTES	Aqua thermal from surface water, industrial HPs, ATES	Solar thermal on roof, HPs, PTES
Secondary source	None	None	None	None
Delivery temp.	70 °C	55 °C	70 °C	75 °C
Ownership	Prefer 100% cooperative, but still researching	Cooperative (>51%) and commercial (<49%?)	Cooperative (>51%) and commercial (<49%), and possibly municipality	100% cooperative
Projected costs for development and realization	€29 million (excl. VAT) for 1.500 WEQs (projected)	€12,5 million (incl. VAT) for 700 WEQs (projected)	Undisclosed	Approx. €1,2 million for whole system (40 connections)

	Lemvig	*Bjerringbrø*	*Viborg*	*Hammel*
Municipality, and location	Lemvig, around the town of Lemvig	Viborg, around the town of Bjerringbrø	Viborg, around the city of Viborg	Favrskov, around the town of Hammel
Status per 06-2022	Exploitation	Exploitation	Exploitation	Exploitation
Since	1964	1959	1964	1957
Connections	4.045 consumers in 2021	2.793 consumers in 2021	11.009 consumers in 2021	4.000 consumers in 2021
Primary source	Biogas CHP, biomass CHP, NG-CHP, Electric kettles	Air-to-water HPs, water-to-water HPs, wastewater HPs with ATES	NG-CHPs, waste-to-energy	Waste furnace, biomass CHP
Secondary source	Biomass boilers and NG-boilers	NG-boilers, NG-CHPs	NG-boilers	NG-boilers and oil boilers
Delivery temp.	70 °C	70 °C	70 °C	70 °C
Building types	Households, offices, industrial, and utilities	Households, offices, industrial, and utilities	Households, offices, industrial, and utilities	Households, offices, industrial, and utilities
Ownership	100% cooperative	100% cooperative	100% cooperative	100% cooperative
Projected costs	n/a	n/a	n/a	n/a

	Neuerkirch-Külz	*Lathen*
Municipality	Neuerkirch-Külz	Lathen
Status per 06-2022	Exploitation	Exploitation
Start year initiative	2013	2008
Realized in	2016	2009
Connections	269	More than 800 as of 2000
Building types	Households and non-residential buildings	Households and non-residential buildings
Primary heat source	Solar thermal on land, wood chip boilers, TTES	Waste heat from biogas, biomass CHP
Secondary source	Oil boilers	Oil boilers
Delivery temp.	70 °C	70 °C
Ownership	100% municipal utility company	100% local cooperative
Project costs	€5 million	€5,1 million for 401 household connections

3.3. Data Analysis

The coding of this study was mainly based on practices from deductive content analysis, although the process featured practices from the inductive approach of grounded theory as well. The process is shown in Figure 3.

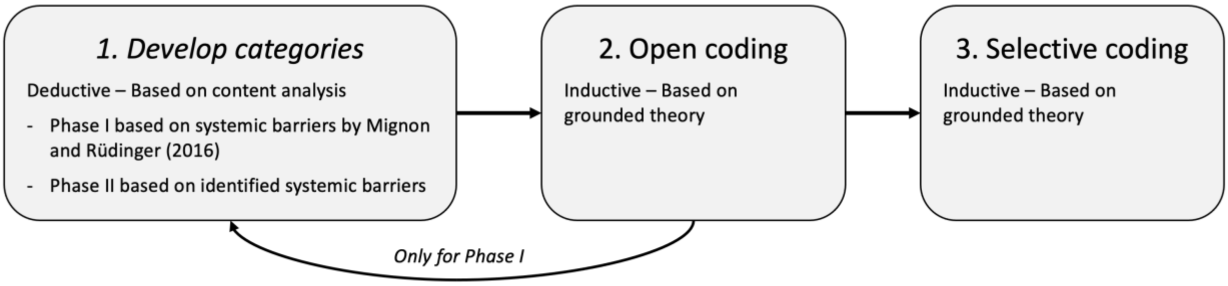

Figure 3. Overview of the coding process.

The first step was to develop a coding framework with categories. Using this deductive approach allowed coding by using the theoretical framework by Mignon and Rüdinger (2016), who identified systemic barriers (Elo & Kyngäs, 2008; Kuckartz & Rädiker, 2019). Using a theoretical framework is crucial according to Yin (2014), as it induces stronger research design and better ability to interpret collected data. The coding framework of Phase II was based on the outcomes of Phase I. The coding frameworks can be found in Appendix B.

After some open coding, however, the coding framework of Phase I, and thus the theoretical framework, was adapted to better reflect the data and to increase reliability (Elo & Kyngäs, 2008). The adapted theoretical framework is shown in Table 5. The theme '*Knowledge and interactions*' was split into three categories that reflect the most important actors: *'TEC and community'*, *'Municipalities'*, and *'Other stakeholders'*. Furthermore, while Mignon and Rüdinger (2016) categorized subsidies into hard institutions, here that is included within *'Financial infrastructure'*.

Secondly, the data was coded according to the practice of open coding from grounded theory (Bryman, 2012). This was done in an inductive way, which means that the codes were not established beforehand, but were immediately placed within their category. The data was turned into small components with a descriptive label, as to develop many codes that describe the data.

Finally, selective coding was utilized, also from grounded theory (Bryman, 2012). By using that method, the codes that were found to be essential and relevant were combined into the identified systemic barrier. All categories were reviewed, and as some did not feature enough data to be robust, not all categories were found to feature a systemic barrier.

Table 5. The adjusted theoretical framework, adapted from Mignon and Rüdinger (2016).

Categories		Definition
Market structure		The structure of the market
Hard institutions	*For DH*	The formal rules within the institutional context and their impact on DH systems
	For TECs	The formal rules within the institutional context and their impact on TECs
Soft institutions		The perceived legitimacy as a result of the social norms, values, and culture
Financial infrastructure		The structures for acquiring financial capital, including equity, loans, and subsidies
Physical infrastructure		The current and required technical structures for the socio-technical system
Knowledge and interactions	*TEC and community*	The capabilities within the TEC and community, and the interactions between the TEC and community
	Municipality	The capabilities of the municipality, and the interactions between the TEC and municipality
	Stakeholders	The capabilities of other stakeholders, and the interactions between the TEC and the other stakeholders

3.4. Validity, reliability, and ethics

Research can be assessed by using the concepts of reliability and validity (Bryman, 2012). To increase *internal validity*, which refers to the integrity of the conclusions that are drawn from the data, practices from the transactional validity approach were utilized within this research. This is grounded in active interaction between participants and researchers (Bryman, 2012; Cho & Trent, 2006). Member checks were conducted, meaning that interviewees were approached afterwards to verify the accuracy of the case study descriptions. In addition, triangulation is applied by using multiple research methods and various sources. This greatly improves the understanding, significance, accuracy, and reliability of the findings, leading to a more consistent, objective picture of reality (Bryman, 2012; Cho & Trent, 2006; Collins & Stockton, 2018). The various sources for verifying statements include reports, annual accounts, and minutes of general assemblies, while multiple-case studies and desk research was conducted. Moreover, using the theoretical framework as a basis for the coding framework ensured the ability to interpret data. Furthermore, *external validity*, which concerns the degree to which findings of the research can be generalizable across a social setting, was assured to some degree by the case study selection (Bryman, 2012). As explained within Section 3.2.2, the cases were selected on a wide range of technologies and size within the three countries.

External reliability deals with the degree to which a study can be replicated (Bryman, 2012). To increase external reliability, the steps taken within this research are explained. For example, the interview guides and coding frameworks can be found within Appendix A and Appendix B respectively. In addition, *internal reliability* assesses the consistency of the results within the research (Bryman, 2012). Although this research was conducted by one researcher, the researcher was aware of possible bias that might occur and has strived for objectivity and transparency. The theoretical framework, interview guides, and pre-established categories within the coding frameworks were utilized to ensure some degree of internal reliability.

To carry out this research in an ethical way, all interviewees were informed transparently about the purpose of this research. Before all interviews, the researcher requested consent for recording and transcribing the interview, to which every interviewee agreed. The consent form can be found in Appendix III. Although the studied cases are not handled anonymously, the interviewees and their information have been treated completely anonymously and confidentially.

4. Results

This section presents the main findings, which are presented in three parts. First, the systemic problems that have been identified in the Netherlands are presented. Second, the Dutch systemic problems are tested on the Danish and German context and case studies. That includes identifying practices that have been used for overcoming or mitigating the systemic problems. Finally, those practices that can be applied to overcome the systemic barriers for TECs in the Netherlands are discussed.

4.1. Results part I: Dutch systemic problems

This section answers the first research question:

> *"What systemic problems do Dutch thermal energy cooperatives encounter?*

Five main systemic barriers were identified in the Netherlands that hamper the development of TECs within this research. Those are the following: *'Financing is crucial but difficult'*, *'Regulatory barriers'*, *'Low legitimacy for TECs'*, *Collaboration with municipality is crucial but difficult'*, and *'Low professionality within TECs'*. An overview of the identified systemic problems is shown in Table 6. The systemic problems influence and reinforce each other and are the result of multiple intertwined factors. Each systemic problem is explained separately below, along with how the systemic problems interact. Those interactions are also shown in Figure 4.

Table 6. All identified systemic problems in the Netherlands between February and July 2022 within this research.

Categories		*Identified factors*	*Systemic problems*
Market structure		Only 1 small-scale TEC in operation	
Hard institutions		Heat supply permit difficult for TECs	Regulatory barriers
		New national heat regulation is limiting for TECs	
		Municipal regulations and procedures not aligned	
		Lack of transparency rules	
Soft institutions		Low reputation of DH due to its monopolistic nature	Low legitimacy for TECs
		Low track record of cooperative DH systems	
		Low track record of aqua thermal technology in DH	
Financial infrastructure		High financial risk in development	Financing is crucial but difficult
		Lack of national financial support instrument	
		Too wide diversity of financing options from municipalities	
		No examples yet on loans for realization and exploitation	
Physical infrastructure		High investments for production facilities	
		High investments for distribution network	
Knowledge and interactions	*TEC and community*	Lack of human capital	Low professionality within TECs
		Lack of equity capital (equity?)	
	Municipality	TECs are highly dependent on municipalities	Collaboration with municipalities is crucial but difficult
		Municipalities are inexperienced with the heat transition	
		Lack of experience in the collaboration between municipalities and TECs	
		Municipal workforce continuation leads to lost knowledge	
	Stakeholders	Some stakeholders are inexperienced with both the heat transition and TECs	

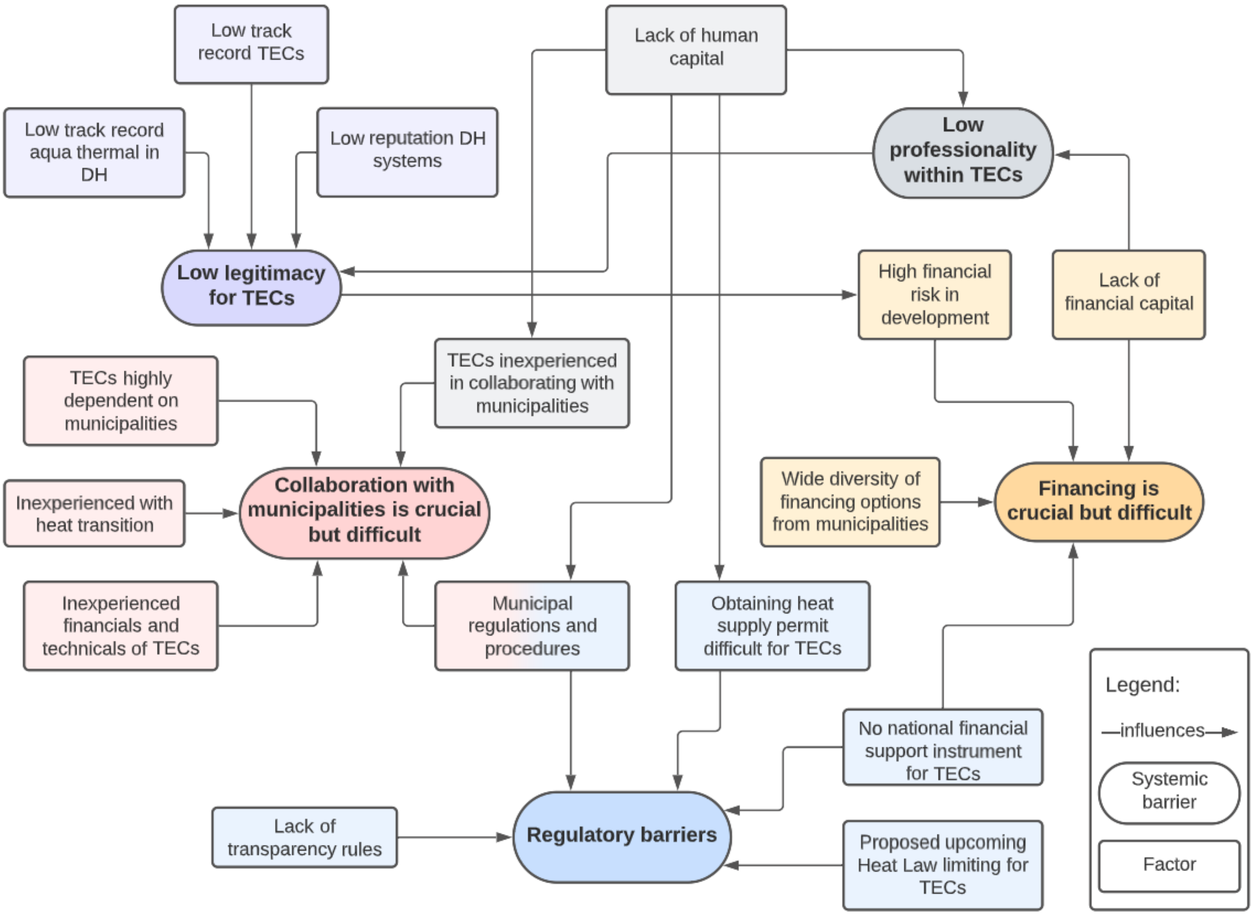

Figure 4. Overview of the identified systemic barriers, their factors, and how those all interact. The box colors of the factors relate to systemic barrier the factor belongs.

4.1.1. Regulatory barriers

As explained within Section 2.3.1, the ACM determines the maximum prices that Dutch heating companies can charge their customers which is coupled to NG-prices. Also, there are rules on what kind of costs heating companies may charge their customers, which were also explained in Section 2.3.1. However, there are no rules regarding how the final prices of the heating company are determined, and no rules on explaining that price development. This leads to unclarities for consumers on how their heating companies are setting their prices and what they are paying for. Furthermore, as heating companies use different pricing formats and different heating contracts, the ACM is only able to monitor large-scale systems but neglects monitoring small-scale systems (CBS & TNO, 2020). INT-01 stressed that increased transparency could benefit the DH sector as a whole as it increases comparability of all heating companies, which will eventually increase trust of consumers towards DH companies. The studied TECs, however, did not experience the lack of transparency rules as a problem.

In addition, the proposed Heat law 2 is set to disadvantage TECs in some ways (INT-02). The exemption for smaller systems of 1.500 WEQs within a heating area, for example, sets a pre-determined size for TECs. Cases Ketelhuis and Panningen both have a higher connection ambition, 3.000 WEQs and 4.779 WEQs respectively. Moreover, TECs are mostly neglected within the proposed upcoming Heat Law. They are The Dutch Climate Accord determines a minimum of 50% collective ownership for renewable energy projects, but this does not apply for heating (Notten, 2020; Participatiecoalitie, 2021).

While the upcoming Heat Law is still in development and the details are unclear, it leads to many municipalities postponing decision-making regarding the development of the new heat supply (INT-02). TECs may experience that as a barrier, although the studied TECs have not experience it that way as they have already received support from their municipalities.

4.1.2. Low legitimacy for TECs

Although the Netherlands knows a strong cooperative history, all cases still experienced low legitimacy towards their project, which was present at both citizens and governmental organizations. This systemic barrier is created by a low reputation of DH, a low track record for TECs, a low track record of the aqua thermal technology, and a low lobby power of TECs. Also, the low professionality within TECs play an important role here, which is further explained in Section 4.1.4.

First, DH systems in general have a bad reputation in the Netherlands, due to their monopolistic nature and lack of transparency around prices (INT-6). That makes citizens distrustful of DH systems in general. Furthermore, although DH brings environmental benefits compared to the current heat system, DH is mainly framed in the Netherlands as “good for the environment” while other aspects such as low fossil fuel dependency, high convenience and stable prices are neglected (INT-01, INT-09). However, many citizens are solely be interested in the best and cheapest systems for their house.

Second, there is also low legitimacy for aqua thermal systems, which is the selected technology in two studied TECs. This is mainly because of less DH systems where the aqua thermal technology is applied (INT-07; Warm Heeg, 2022). In the Netherlands, as of 2021, there were only 80 aqua thermal projects realized, of which few in neighborhoods with more than 100 houses. Moreover, most of those aqua thermal projects are realized in new-built neighborhoods and a large part (almost 50%) supplies utility buildings, such as offices and swimming pools (NAT, 2020). None of the aqua thermal projects were realized by TECs. This may explain why for project Ketelhuis citizens questioned aqua thermal as a solid technology for their heating supply and would rather opt for a well-known system rather than air-to-air HPs (INT-03).

Third, there is still a lack of imagination present with citizens and municipalities that the cooperative model can work for DH (INT-02; INT-09). RECs in the Netherlands are already highly established and have thus proved themselves, while there are only two TECs operational. This makes citizens reluctant for connecting to cooperative DH systems. Additionally, municipalities may lack trust in the professionality of TECs, and therefore choose commercial heating companies over for developing DH systems (TNO, 2020).

Fourth, the six large commercial heating companies have an enormous influence on policymaking, while smaller heating companies, including TECs, lack lobby power due to their smaller size and smaller amount (INT-01). Energie Samen acts as a lobby organization for all TECs by advocating the cooperative interests at the national level (INT-02). In the beginning, the organization was not taken serious by the national government, but the relationship with the national government has recently improved and is now perceived as constructive (INT-09). This improvement is mainly due to the increasing number of successful RECs and higher professionalization of Energie Samen.

Finally, there is still a knowledge gap at the central government regarding the ambition and activities of TECs (INT-02; INT-09). The government, for example, is prone to think TECs only develop small-scale projects (less than 100 WEQs), while cases Ketelhuis, Panningen, and Muiderberg have shown that TECs develop larger projects as well (more than 1.000 WEQs). Moreover, TECs can acquire increased legitimacy through governmental measures. This was shown with the PAW-grant. When Ketelhuis and Panningen obtained the PAW-grant, this greatly improved the trust of the municipality, community, and other stakeholders towards the initiative, and thus the power of the TEC to further develop.

4.1.3. Financing is crucial but difficult

All studied cases, but especially Ketelhuis and Muiderberg, found financing the most important barrier in their development so far. TECs require financial capital to hire external knowledge to overcome their lack of human capital and develop the business case and designing the technical system. However, TECs lack financial capital from the start due to their grassroots nature. When they don't acquire financing, the cooperative low-carbon heating system cannot be realized. Acquiring financing is difficult, as private banks perceive TEC projects as high-risk, and a national subsidy for TECs is lacking.

For almost all cases the physical infrastructure (i.e., production facilities, distribution network) still had to be constructed as their heating supply is based on NG-boilers. This involves large investments in the production and distribution facilities. Only the distribution system of Duinwijck was already in place. The distribution system and production facilities (solar thermal, PTES, and HPs) of Duinwijck still had to be constructed and implemented, and buildings had to be adjusted to adopt the new sustainable heat system.

As explained within Section 2.1.2, there are the following three types of financing for TECs: equity, loans, and subsidies. Table 7 shows the identified financing options per case study, and those are further explained below.

Equity

Ketelhuis, Panningen and Muiderberg are charging connection fees to future customers. Customers can fully compensate those connection fees through the national investment subsidies ISDE (for homeowners) and SAH (for rental properties of housing associations). To access the subsidy, homeowners must apply themselves. Therefore, Ketelhuis, Panningen, and Muiderberg are charging the maximum fee that customers can compensate. Duinwijck is not charging a connection fee to their customers, as their system has been running since 1999 although by another owner. The TEC is expecting to take over operations from the previous owner with a newly installed low-carbon system at the end of 2022 but is therefore unable to charge a connection fee due to existing regulations.

Of the studied TECs, Panningen, Muiderberg and Duinwijck have had access to private equity. Panningen and Muiderberg could rely on equity from shareholders. Also, Panningen used earnings from their own wind turbines. Moreover, Panningen has been collaborating with their system developer since the beginning, which has invested an undisclosed amount into the project in return for ownership of the cooperative. That shareholder position still needs to be determined but will be a minor stake.

Table 7. Identified financing options from the studied Dutch TECs.

		Ketelhuis	Panningen	Muiderberg	Duinwijck
Projected costs for development and realization		€29 million (excl. VAT) for 1.500 WEQs (projected)	€12,5 million (incl. VAT) for 700 WEQs (projected)	Undisclosed	Approx. €1,2 million for whole system (40 connections)
Equity	*Connection fee*	€3.325 per building	€3.325 per building	€3.325 per building	
	Shareholder capital		Undisclosed, from technical partner	Undisclosed, from shareholder capital	
	Own capital		Undisclosed, from wind energy earnings		
Subsidy	*Municipality*	€175,000 in 2019		€70.000 in 2019	
	Province	€50,000 in 2019		€130.000 in 2019	
	PAW	€7,7 million 2020	€4 million 2022		€1,1 million in 2019
	SDE				€151.000 from SDE+ in 2020
	Other				€365.000 from VNG in 2018
Loan		Still researching and discussing	Still researching and discussing	€1,5 million (2,5 % interest rate) from municipality	
Other					Benefited indirectly from financial investments of former owner

Subsidies

Municipalities and provinces can help financing the development phase, but this is highly dependent on their capabilities and willpower. For example, Ketelhuis and Muiderberg have received multiple subsidies from their municipality and province, as shown in Table 7. In addition, Muiderberg acquired a loan of €1,5 million from their municipality for development, which does not have to be repaid if the project fails. This loan, however, led to concerns around state support. Contradictory, cases Panningen and Duinwijck did not receive any subsidy from their municipality and province. The municipality of Panningen supports the project but announced in an early stage that they were not going to support through financing. While the municipality of Duinwijck did not have the financial capabilities to support through subsidies. However, Duinwijck did obtain a subsidy from the association of municipalities (in Dutch 'VNG').

Currently, only the national grant from the *Program Natural-gas free Neighborhoods* (in Dutch 'PAW') is available for TECs as a national subsidy program for the development phase. This subsidy is part of a learning program, with the aim to learn how the neighborhood approach can de designed and scaled up for the heat transition. Only heating initiatives that will provide new insights are selected, which means that only a small portion obtains the PAW-grant. All studied cases deem the PAW-grant essential for closing the business case, as it is the only national subsidy program available. While all studied cases applied for the grant, only three of them (Ketelhuis, Panningen and Duinwijck) have been granted the PAW with different amounts. Muiderberg has applied and been denied the PAW two times as the commission expected their project to not yield new learning outcomes. For them, this has led to uncertainties and development delays, as they were planning to cut costs by combining the implementation of a DH system simultaneously with municipal sewerage renovations.

Although only case Muiderberg did not obtain the PAW-grant, all studied cases found the fact that the PAW-grant is only there for learning outcomes a systemic problem.

Another available subsidy is the SDE++, for which all DH project initiators that use renewable energy in the system can apply. This subsidy covers the unprofitable peak between the exploitation cost prices and market prices. All cases included this subsidy within their business case, although obtaining is only possible when the business case is finalized, and permits are received. After obtaining SDE++, the project must be operational within four years, otherwise the project has to apply again. Only Duinwijck has so far been able to obtain this subsidy, as the other cases are still in development.

Loans

Obtaining loans from financial organizations have been discussed by Ketelhuis, Panningen, and Muiderberg. Only Duinwijck has been able to close the business case without loans. Banks are hesitant and perceive cooperative heating projects as high risk, due to the lack of successful stories (Henrich & Maas, 2020). In addition, banks may perceive TECs as unprofessional and not being creditworthy (INT-01, INT-07). Ketelhuis and Panningen showed that the further the project, the higher the willingness from banks to discuss financial terms. This highlights the need to have a track record and establish trust between financial organizations and TECs.

Due to the high investments required for DH systems, long depreciation periods (usually above 30 years) are necessary for the project to become economically profitable (TKI Urban Energy, 2020). Commercial banks, however, treat energy cooperatives the same as commercial companies, with high interest rates and short repayment schemes of up to 15 years (INT-02; van der Windt, n.d.). However, according to INT-03, some banks in the Netherlands desire to be frontrunner through having a cooperatively heating project in their portfolio. This is confirmed by INT-06:

> *"Our talks with banks are better than two years ago, because our business case is getting more concrete. We have also noticed a turning point within banks, that are currently more inclined to think about financing for more than 15 years. That growth process is happening within banks."*

Muiderberg experienced that banks require a guarantee from the municipality in order to provide financing, as banks often perceive TECs as high-risk investments. Their municipality, however, has denied guaranteeing. According to INT-10, only public banks can finance TECs for periods longer than 15 years, maybe even 30 or 40 years, depending on the business case and whether the municipality provides a guarantee.

Other

All studied cases have been searching for ways to save on the high investment costs of the distribution network, Muiderberg, for instance, aims to implement it simultaneously with the planned infrastructural renovations of the municipality. Panningen has researched another possibility; co-ownership of the distribution system with the municipality or local network operator, so that they bear those investment costs. The alignment of different infrastructure plans, however, is not always possible as the requirements of the municipality need to be aligned with the timelines of the TEC.

Duinwijck has indirectly benefited from investments into the DH system by the former owner, which is an exceptional case. The owner renovated the system and constructed a new technical building with the right properties for the newly to be built system. Also, one employee of the former owner was available for all kinds of questions and supported with legal aspects. This was all done in return for a small amount of money (€10.000) but relieved the TEC of a large amount of costs and helped them overcome the lack of financial capital. Duinwijck calls this a "wedding gift" from the former owner, and the benefit in terms of money was significant for them.

4.1.4. Low professionality within TECs

All cases have experienced a low professionality within their TEC to be hampering their development. This is mainly due to a lack of human capital.

The existence of a professional network within the organization and community to contact professionals can be important. Only Ketelhuis has been able to draw from existing professional networks within their community. In the beginning, they invited 10 market parties from their network to present ideas for making the neighborhood NG-free. Furthermore, access to experienced individuals from the TEC and community is important. Especially Ketelhuis and Muiderberg have been able to draw expertise from their project group and volunteers within the community. As INT-07 from Muiderberg highlights:

> *"We are a societal organization, and there is a lot of expertise around the corner. Those people have knowledge on all kinds of matters, and motivation for committing to a societal purpose. That's a lot of talent, locally available."*

Still, all cases are depending on external knowledge for developing the business case, designing the technical system, and legal matters. Cases have experienced the web of regulations and legal procedures to be especially hampering. Both Panningen and Muiderberg have hired legal expertise to overcome that problem. Regarding the technical system, TECs can suggest ideas (such as preferences for a heat source) but have limited capabilities to design the system themselves (van der Windt et al., 2021). The decision for the technical system, however, is entirely for the TEC to decide. As explained by INT-06:

> *"For sure there are things we don't understand as a cooperative, for which we need the right external expertise."*

When projects are becoming more complete, the responsibilities of TECs increase (INT-07). Professionalization increases trust of the community, municipality, and other stakeholders regarding the cooperative, which is necessary for e.g., signing contracts and acquiring permits. Furthermore, knowledge and experience regarding the technical system is necessary in case of system malfunctions.

For obtaining knowledge and support Ketelhuis, Panningen and Muiderberg have actively sought interaction with Energie Samen. Energie Samen is the overarching cooperative association of energy cooperative. Originally, they focused on renewable energy, but since the grow of heat initiatives they have expanded their focus towards thermal energy. For heat cooperatives their mission is to:

“Enable citizen initiatives to play a full-fledged role in the heat transition by supporting them in every phase and every step.” (INT-02)

As a knowledge institute their aim is to help TECs professionalize by providing them support and training. They acquire and combine knowledge by letting their members (TECs) conduct projects. According to INT-01, Energie Samen can support TECs for the largest part of development. Only, Duinwijck did not seek contact with Energie Samen, as the TEC was hesitant on their capability.

Also, for acquiring a heat supply permit, TECs require a level of professionalization that they have not had before. This because the ACM demands administrative, technical, and organizational capabilities before granting the heat supply permit. Of the cases, only Ketelhuis has applied for such a permit in collaboration with Energie Samen which they have not yet received. Duinwijck was the only studied case that does not need the permit, as it will supply less than 10.000 gigajoules per year.

4.1.5. Collaboration with municipalities is crucial but difficult

As stated within the Dutch Climate Agreement, and given the local nature of heat, municipalities have been assigned the directing role in the heat transition (Herreras Martínez et al., 2022). Before 2021 every municipality must have determined a local heat planning per neighborhood with timeline, and every studied TEC was mentioned in the Transition Vision Heating of their municipality (PAW, 2022). In addition to spatial planning, TECs rely on municipalities for environmental and constructional permits, and subsidies. TECs find the regulations and procedures to be the most difficult in collaborating with the municipality, while they have also encountered low levels of experience present at municipalities regarding both DH and TECs.

The role of the municipality can range from co-creation to facilitating partners, but sometimes the collaborations with municipalities are difficult. The results indicate that the municipality is often inexperienced with the heat transition and its innovations, including collaborating with TECs, which is sometimes due to their smaller capacity. An overview of the interactions with the municipality can be found in Table 8.

The municipality of Panningen is collaborating, but not willing to support through financing the project. The collaboration between Ketelhuis, Muiderberg and Duinwijck, however, is willing to support through financing. Their municipalities have developed the local policy context to make more supportive arrangements for the TECs. The municipality of Ketelhuis, for example, developed a networking platform for regional ECs to share knowledge and has a dedicated subsidy program for initiatives developing sustainable energy systems (Amsterdam, 2020). Furthermore, their municipality has the capacity to assign one director to TEC initiatives further in development (INT-05).

The municipality of Muiderberg entered into a strategic partnership with the TEC in 2020 for three years, which is likely to be extended. They have also planned to implement DH pipelines simultaneously with local sewerage renovations, so that the TEC can save costs, and have provided a loan to the TEC for development and realization, which has not been done in another Dutch TEC. The municipality of Duinwijck actively sought for a TEC to make the existing DH system more sustainable and was therefore guiding TEC development from the beginning.

Table 8. Identified capabilities of and interactions with the municipalities of the studied Dutch TECs.

		Ketelhuis	*Panningen*	*Muiderberg*	*Duinwijck*
Interactions with TEC		Regards the TEC as a learning process for municipality, and collaborate intensively	Collaborating but municipality is not willing to subsidize	Strategic partnership with the TEC for three years with chance of extension	Actively sought a TEC for making existing system NG-free
Mentioned in municipal heat transition plan		Yes	Yes	Yes	Yes
Helped with financing		€175.000 subsidies in total		€70.000 subsidies in total, and €1,5 million loan	
Problems	*Experience with DH*	Somewhat experienced due to large size and existing DH systems in the city	Inexperienced	Inexperienced	Inexperienced
	Experience with TECs	Only experienced with REC	Only experienced with REC	Only experienced with REC	Only experienced with REC
	Regulations	Subsidy regulations do not align with PAW-grant, still not fully received	Subsidy regulations do not align with PAW-grant, still not fully received	State support concerns regarding the loan	Subsidy regulations did not align with PAW-grant, had to change
	Other	Slow processes and constant in municipal workforce		Slow processes and constant in municipal workforce	

All cases have highlighted the inexperience of the municipality regarding the heat transition, but also the willingness of municipalities to collaborate. For Ketelhuis and Duinwijck, for example, the aim of municipalities has been to learn by doing in the heat transition by stimulating the heat initiatives. Panningen, Muiderberg and Duinwijck have found their municipality to be inexperienced with the heat transition, DH, and its innovations, which has made collaborating with them difficult. Problems relate to understanding the business case and technical systems of DH systems in general, but also of TECs. As INT-08 explained:

> *"What the municipality, and many other people, don't understand, is that assumptions within the business case are made for the next 40 years."*

Although all municipalities have had experience in collaborating with ECs in general, none of them had experience in collaborating with TECs. Furthermore, there is a wide variety in capacity for dealing with the heat transition and TECs. Therefore, as identified by Herreras Martínez et al. (2022), many municipalities are highly dependent on external knowledge during local heat planning.

Furthermore, all studied TECs have had problems regarding the regulations of municipalities, while the municipalities sometimes have had difficulties with the regulations themselves as well. For example, the subsidy regulations of the municipalities for Ketelhuis, Panningen and Duinwijck were not aligned with the large subsidy amount of the PAW-grant. This is explained by INT-03:

> *"You forget that the municipality can never, without conditions and subsidy regulations, give money to others, and that holds for everyone and every project."*

Therefore, the subsidy regulations of all municipalities had to be adapted, which is a time-intensive for officials (INT-05). Duinwijck has received the PAW-grant completely, while Ketelhuis and Panningen had to submit detailed plans for small portions of their approved grant. Another example is the municipality of Muiderberg, which decided to loan €1,5 million to the TEC. That loan, however, was met with concerns around state aid, and the municipality and TEC therefore hired legal firms to alleviate those concerns.

TEC Panningen hired a legal firm to overcome the lack of knowledge and experience regarding regulations and procedures with their municipality, which increased the trust of the municipality over time. This led to the municipality willing to let the TEC do documentation for the PAW application.

Differences can be experienced within municipalities, as every department within municipalities is necessary for the heat transition (INT-07). One department (e.g., finance) can be supporting and accommodating, while another (e.g., permitting) is not (INT-02). Furthermore, all cases have mentioned the constant changes within the municipal workforce. For Ketelhuis this has been one of the most difficult parts in collaborating, as they had to make new agreements constantly. This is supported by a municipal employee (INT-05). A lot of knowledge is getting lost when the municipal workforce changes constantly.

4.2. Results part II: Challenges and solutions from Denmark and Germany

In the former section five main systemic barriers have been identified that Dutch TECs have encountered in their development. This section aims to find whether those barriers have been present in Denmark and Germany, and what practices can be found in those countries to alleviate them. Therefore, this section answers the second and third research questions of this study simultaneously. Those are:

RQ 2: How did Danish and German thermal energy cooperatives encounter the systemic problems that were found in the Netherlands?

RQ 3: What practices allowed Danish and German thermal energy cooperatives to mitigate and/or overcome those systemic problems?

The sub-questions are answered per systemic barrier and are explained below.

4.2.1. Regulatory barriers

Denmark did not encounter the systemic barrier "*Regulatory barriers",* instead it seems that the regulations are highly favorable currently for TECs, including the standardized heating contracts, cost-based pricing, Non-Profit Principle, and voluntary benchmarking. However, the German TECs, lack national regulations for DH. The introduction of the feed-in compensation for residual heat of biogas CHPs seems to be important in the increase of TECs. An overview can be found in Table 9.

Table 9. Overview on the systemic barrier "Misaligned regulations for TECs" in Denmark and Germany.

	Denmark	*Germany*
RQ2: How encountered?	Regulations are aligned towards TECs	No national DH regulations
RQ3: What practice?	Standardized heating contracts	Introduction of feed-in compensation residual heat from biogas CHPs
	Cost-based pricing	
	Non-Profit principle	
	Voluntary benchmarking	

Denmark

All studied cases agree on the Non-Profit principle as a major reason for the ability of TECs to compete with other heating sources. This has the additional benefit that, as no returns are expected, that heating companies can make business cases with payback periods up to 20 years (INT-12; INT-13).

Furthermore, the mandatory transparency regarding heat prices and the voluntary benchmarking helps consumers to monitor their heating company when necessary. Furthermore, cost-based pricing allows TECs and other heating companies to only charge the necessary costs. The mandatory transparency, voluntary benchmarking, non-profit principle, and cost-based pricing have been a major force for Danish heating companies to constantly investigate ways to lower the heating prices. For example, the TEC in Lemvig is very proud to have the third-lowest heating price of the country. In addition, all cases mentioned the ability of consumers to appeal to the board and ask questions during the yearly general assembly.

The obligatory connection ability of municipalities has been a major factor for success of all studied cases. That regulation legitimized TECs to expand into new areas and ensured secure income streams. This was found to significantly lower the risk of new investments, and thus also the “off-take risk”. Before the regulation was abolished in 2019, the TECs and Dansk Fjernvarme opposed that decision for fear that customers would choose other heating options (Dansk Fjernvarme, 2021; INT-14; INT-17). However, until now customers still seem to prefer DH connection over other options.

Germany

Germany does not have national regulations for DH. The lack of rules around standardized heat contracts, heat tariffs, and monitoring, did not seem to hold back the development of the studied cases, although the Renewable energy act seems to have had a strong impact on the formation of bioenergy villages (Roesler & Hassler, 2019). Both cases have been initiated by local farmers that wanted to find another purpose for their residual heat, after the feed-in compensation of Renewable energy act was introduced. This shows that the feed-in compensation has had a positive influence on the formation of both studied cases, but also throughout the country.

4.2.2. Low legitimacy for TECs

Denmark and Germany both have a strong cooperative history. In addition, the large track record of successful TECs in Denmark, which started around 1920, has led to high trust of citizens regarding TECs. In addition, DH in Denmark is framed as providing lower costs and higher convenience, while the TECs in Germany were founded mostly with the aim to provide benefits for the community. Furthermore, cooperative organizations in Germany were dealing with an old-fashioned image, which they reduced through marketing campaigns and lobbying at institutions. An overview is shown in Table 10, which is further explained below.

Table 10. Overview on the systemic barrier “Low legitimacy” in Denmark and Germany.

	Denmark	*Germany*
RQ2: How encountered?	Strong cooperative history	Strong cooperative history
	High trust in TECs	Cooperative organizations dealt with an old-fashioned image
RQ3: What practice?	DH framed as low cost and high convenience	Marketing schemes to get rid of “old-fashioned cooperative image”
	Environmental and social benefits are less important	High support from municipality
	Lobby collectively at national government	TECs embedded in local community

Denmark

Denmark has a long history with the cooperative model, which was particularly present with agricultural cooperative movements (Chloupkova et al., 2003). This success allowed for an easy translation to the electricity and heat sector (INT-17; Johansen & Werner, 2022). Already in 1920, some CHP-plants were community-based for supplying heat to their neighborhoods (Kooij et al., 2018). In addition, as examples of failing heating companies are hard to find, citizens have high trust regarding cooperative DH systems (INT-17).

In addition, Dansk Fjernvarme lobbies collectively for all its members at the national government for attractive policies. Its members include 99% of all Danish heating companies, including cooperative, municipal, and private companies. All cases agreed that they benefit from the collective lobby, although case Viborg mentioned that they and the larger heating companies are lobbying themselves at the Danish government as well. This, because interests sometimes differ greatly within the country. For example, what is in the interest of a TEC with heating from waste incineration, might be different than for a TEC relying on solar thermal.

Furthermore, due to the long history of Denmark with DH, people are aware of the benefits it brings to their heating supply, which are cheaper heating costs, higher convenience and greater environmental benefits compared to other heat sources (INT-14). The benefits of DH networks, however, are mainly framed around cheaper heating and higher convenience, and that seems to resonate with the consumers (DEA, 2017). According to INT-14:

> *"People want district heating because it is really easy, they do not have to hassle with all the facilities installations."*

Environmental and social benefits are mostly playing in the background. Since the war in Ukraine heating companies are experiencing a huge influx of new customers, which can be due to social concerns to reduce fossil fuel independency. But here, again, the main motivation for DH connection are the cheaper heating costs compared to the rising NG-prices.

Germany

The German cooperative legal form was considered outdated up to 2006, after which it gained traction again (BMWi, 2015). Now it is seen as a suitable organizational form for citizen movements, which is mainly due to intensified marketing campaigns, lobby actions, and a rethinking of the economy after the financial crisis, which have all led to a change in cooperative laws that increased the attractiveness of the legal structure (Punt et al., 2022). A Those marketing campaigns originated from citizen movements and traditional cooperative divisions (e.g., banks, housing cooperatives, consumer cooperatives and rural cooperatives) and were mostly aimed at institutional organizations, focusing on increasing the knowledge and image and reducing bureaucracy (BMWi, 2015).

The two German cases have both benefited from high community cohesiveness and the support of the mayor. The TEC in Lathen specifically benefited from discontent among citizens regarding their current NG-supplier, and the community therefore welcomed the DH initiative with open arms. After establishing the DH network, the cost of DH heating was less than the costs of heating from NG. The initiative of Neuerkirch-Külz was initiated by a small working group within the municipality, who perceived the heat initiative as a means to realize a more sustainable village.

4.2.3. Financial infrastructure

The TECs in Denmark are not having problems for funding development and realization of new projects (see Table 11). Loans can be acquired for DH infrastructure facilities from both commercial and public banks with the municipalities guaranteeing, by which investments are regarded as low risk. That is also due to the secured income stream of TECs and their high track record. Furthermore, an investment subsidy is available expanding into new areas to help TECs with breaking even.

Table 11. Overview on the systemic barrier "Financing difficult for TECs" in Denmark and Germany.

	Denmark	*Germany*
RQ2: How encountered?	No systemic problems for funding development and realization	Lack of national financing mechanism for development phase
		Financing of development phase is high risk
RQ3: What practice?	Low-interest loan available from public bank (Kommunekredit) with municipality guaranteeing	Low-interest loan available from public development bank (KfW) with municipality guaranteeing, including redemption grant
	Environmental and social benefits are less important	Municipalities support by financing development and connection fees

In Germany, the TECs seem to have problems for funding the development and realization phase, although the studied cases have been supported significantly by their municipalities. Municipalities have subsidized the feasibility study and connection fees for households. Also, the loan from the German development bank (KfW), for which the municipality must guarantee, is of significant importance in realizing the TEC as it improves the business case.

Denmark

All studied TECs always opt for loans from Kommunekredit, a credit that TECs can access through their local government. Kommunekredit is an association of all Danish municipalities and regions that can offer financing at the lowest possible cost and with equal terms, with the aim to enable municipalities and regions to create the most sustainable solutions. All members are jointly and severally liable for liabilities of Kommunekredit, which allows the association to borrow at low interest rates. Before TECs can acquire such a loan, the municipality must guarantee the project. Typically, the loans have low interest rates (usually below 2%) and long time periods (between 20 and 30 years) when the municipality is guaranteeing. Viborg, for example, acquired a loan for two HPs for 16 years against a fixed rate of below 1%. In addition, all studied cases highlight the ease of access to loans from Kommunekredit.

Another option is loans from commercial banks. Investments into DH infrastructure (network and production facilities) are generally regarded as low risk. The reason for that is the historical monopoly of heating companies within an area due to the connection obligation, leading to a secured income (INT-13). The interest rate of loans offered by commercial banks to heating companies is approximately the same as that by public banks (around 2%), as it is based on the customer base and value of facilities.

There is one investment subsidy available in Denmark, also known as the "*Fjernvarmepuljen*", with the aim to replace individual oil and gas boilers with connections to energy-efficient DH (DEA, 2022). Heating companies can apply for up to €2.650 per converted oil and gas boiler, for the minimum required connection amount for the company's finances to break even. Of the interviewed cases, only Viborg has applied so far for this subsidy as they plan to expand their heating network.

Germany

In Germany, the development phase of TECs is regarded as high-risk, while there is no national program available for getting through development (Roesler, & Hassler, 2019). For the researched cases, only the municipality of Neuerkirch-Külz fully financed the development phase of the TEC, while development of Lathen was completely financed by its local bank.

Both cases raised equity capital through charging fees for the connection and implemented heat exchangers per house. Lathen charged €4.100 for every new connection and installed heat exchanger. Case Neuerkirch-Külz charged €4.000 per connection, including the heat exchanger, although the municipality completely subsidized this fee for every new connection with their incomes from wind turbines.

Heat supply networks may apply for financial credits for realization and exploitation, including repayment grants from the German development bank (KfW), as part of their "Renewable Energies – Premium" program and the Renewable heat act. This program finances heating from renewable energies, such as heat networks, solar collector systems and industrial heat pumps, and aims at owners and/or operators of the system which can be cooperatives, municipalities, companies, and farmers (Girlada & Rodrigo, 2016). The KfW demands security through a debt guarantee from the municipality, as they have significantly higher creditworthiness than TECs. The German TECs where local authorities took the risk for guaranteeing credit were found more likely to be successful, according to Roesler and Hassler (2019). Only case Neuerkirch-Külz received credits from this program of the KfW; €1,1 million with an interest rate below 2% in 2015, as this program did not yet exist during development of case Lathen. In addition, financing from banks may be an option, as shown by Lathen which received €2,9 million from their local bank, which was one of the initiators of the project.

In addition, TECs may receive subsidies from special programs of their federal state (Roesler, & Hassler, 2019). Lathen, for example, received subsidies of €1 million in total from the KfW and its federal state in 2008. While Neuerkirch-Külz received a subsidy of €480.000 in 2015 for regional development.

4.2.4. Low professionality within TECs

The studied cases in Denmark (especially the smaller TECs) and Germany seem to experience the lack of human capital as a systemic barrier (see Table 12). However, in Denmark the strong networks between the TECs and sometimes with the municipal utility company help overcome that barrier by sharing knowledge, employees, and tenders. Also, the merger of TECs and small TECs being acquired by larger heating companies (including TECs) helps by combining human capital. In Germany, there are large ECs and municipal utility companies that operate multiple smaller TECs.

Denmark

All studied TECs employ several system engineers in their teams, and thus have internal basic technical knowledge. They are, however, still dependent on external knowledge (for financial, technical, and legal support), which they can easily hire within their local region (INT-12). The larger the TEC, the more internal capabilities available and thus the less external knowledge is required.

Table 12. Overview on the systemic barrier "Low professionality within TECs" in Denmark and Germany.

	Denmark	*Germany*
RQ2: How encountered?	Basic internal human capital, but small TECs still lack human capital	Small communities lack human capital for TECs
	Challenges such as the green transition, administrative tasks, and rising NG prices	
RQ3: What practice?	TECs are merging into bigger cooperatives to overcome lack of human capital	Larger energy cooperatives operate multiple small TECs
	Sharing knowledge, employees, and tenders	Municipal utility companies operate small TECs
	Strong networks between TECs	

Due to increased regulations (e.g., regarding privacy), administrative tasks have increased over the years, which puts more stress on their administrative workforce (INT-16). This is challenging for smaller heating companies, as they sometimes lack human capital and financial autonomy. In addition, the green transition may be highly challenging for DH projects that are still highly dependent on NG, as it requires additional investments to shift to a cleaner heat source, and additional knowledge and experience for designing a new technical system. Furthermore, the rising NG-prices lead to some heating companies experiencing higher heating prices due to their fossil fuel dependency, which puts additional stress on their customer relations (INT-14).

All cases highlighted the strong networks between TECs, and good relationships with municipal heating companies. TECs are often helping each other by exchanging knowledge and employees (INT-12; INT-13; INT-14). Larger heating companies may feel a "big brother responsibility" to companies in their region and interact frequently with smaller heating companies (INT-13). Especially Bjerringbrø and Hammel highlighted their dependence on the larger companies in the region and expressed their desire for even more interactions. While Lemvig and Viborg highlighted their interactions with smaller TECs and their ability to help. In addition, heating companies sometimes help each other by combining their tenders of infrastructural construction for market parties, to receive lower prices (INT-13). Furthermore, all studied TECs mentioned they interact with Dansk Fjernvarme, although the association seems to interact more often with smaller TECs. Dansk Fjernvarme helps TECs by advising them on all kinds of matters, including the privacy laws, consumer relations, business case and the green transition.

As a solution to the lack of human capital, small TECs are sometimes merging in one larger entity to combine human capital and stabilize heating prices (INT-13; INT-14). Viborg is an example of a merger between four heating companies within the city, which was done to overcome the lack of human capital. This brought efficiency gains and cost savings. Also, larger TECs or municipal heating companies may sometimes acquire smaller TECs for the same reasons as above. The municipality of Aalborg, for example, is acquiring smaller TECs in their region which often require help, to help them stabilize heating prices through connecting the DH networks. This leads to the ability of using different heating sources.

Developing new TECs need to develop a positive business case of a new technical system. This requires external support from consultancies, existing heating companies, and Dansk Fjernvarme (INT-13). Dansk Fjernvarme is the cooperative association of all Danish heating companies and provides knowledge and tools on all operations related to DH. They also provide courses for all Danish heating companies. Hammel, Lemvig and Bjerringbrø mentioned that they often contact the association for obtaining knowledge.

There are only five known initiatives for new TECs (INT-17). Hiring a consultancy requires initial financial capital. Existing heating companies may support other heating companies free of charge, although they are often unable to provide the required support due to their capacity (INT-13). When the municipality approves the heat plan, the TEC can apply for the same loans from Kommunekredit as any other heating company (INT-13).

Germany

The studied cases in Germany both have had problems regarding the lack of human capital. Lathen relied extensively on consultancies and local engineering firms for project development. They have been able to own and operate the DH system themselves, with only one engineer in employment.

Neuerkirch-Külz lacked the knowledge and experience already in the beginning for project development, and to overcome these problems and the lack of human and financial capital, opted for collaboration with the regional utility company. That company took over development without the aim of profiting and is now owning and operating multiple DH systems in the region. This allows its customers still have indirect control over their system. More cases like that can be found within Germany, and there are even multiple larger cooperatives (e.g., Bürgerwerke and SolarComplex) owning and supplying DH systems throughout the country. The number of those ECs are unclear, as TECs are not monitored.

4.2.5. Collaboration with municipality

The studied TECs from both Denmark and Germany have experienced the collaboration with their municipality as guiding, as shown in Table 13. There are differences, however, in the responsibility of municipalities, which impacts the way of collaborating. In Denmark municipalities have the mandatory responsibility for heat planning with the largest socio-economic benefits, including some abilities such heat project approval, zoning, and the abolished obligatory connection regulation. To reduce the knowledge gap of municipalities in the beginning and enable them to fulfill their responsibilities, a detailed catalogue of possible technologies for DH systems and a standardized national methodology for choosing the best heat technology was developed. The municipalities in Germany do not have that responsibility, although some voluntarily initiate and collaborate with TECs with the main aim to provide value to their community. There, the highly supportive and facilitative municipalities were found to be essential for the TECs.

Table 13. Overview on the systemic barrier "Collaboration with municipality essential but difficult" in Denmark and Germany.

	Denmark	*Germany*
RQ2: How encountered?	Lack of experience of municipalities in the beginning on local heat planning but that is overcome	Lack of experience of municipalities in local heat planning and collaborating with TECs
RQ3: What practice?	Municipalities have responsibility for heat planning	Municipalities have no responsibility for heat planning
	Obligatory connection regulation	Municipalities were highly supportive and facilitative
	Detailed technology catalogue	
	Standardized methodology for municipalities with yearly updates	

Denmark

Municipalities are the most important stakeholder for heating companies, as municipalities are responsible for preparing and updating municipal heat plans and for approving heat projects (DEA, 2017). Therefore, all heating companies operate in close collaboration with the municipalities, and all studied TECs regard the collaboration with their municipality as guiding.

Municipalities are mandatory to finalize heat plans by the end of 2022, so that every building in the municipality knows their future sustainable heating options (INT-14). Smaller towns with heating still based on NG grids or oil and NG boilers have three options for phasing out natural gas: (1) installing individual HPs, (2) connecting the area to DH from a nearby heating company, or (3) setting up a new heating company with new DH facilities. For the third option, the municipality must designate the area as having potential for DH, after which potential customers are searched.

The municipalities are responsible for approving the heat projects of heating companies that must be made in case of major changes to the existing DH system. Different project plans must be developed, which are analyzed by the municipalities. When municipalities acquired responsibility for heat planning in 1979, they had little experience with heat (DEA, 2012). To overcome the lack of experience, the DEA developed a detailed technology catalogue with standardized information, and a techno-economic methodology so that municipalities can assess the socio-economic impacts of the project plans and develop accurate cost estimates themselves (DEA, 2017; Styregruppen for Forsyningskataloget, 1988). This methodology is still being used up to this day and is essential for all municipalities in their local heat planning efforts.

The methodology has several assumptions, including fuel prices, electricity prices, interest rates, and externality costs of emissions. In addition, the DEA updates its forecasts for future energy prices, future energy use, and other necessary considerations yearly. Within that framework, there is enough room for municipalities to adjust the methodology for local priorities. Municipalities are obliged to choose the project plan with the largest socio-economic benefits.

The obligatory connection ability of municipalities was a major factor for success of all studied cases. It was removed to reintroduce complete freedom of choice. The regulation legitimized TECs to expand into new areas and ensured secure income streams. This was found to significantly lower the risk of new investments, and thus also the “off-take risk”. Before the regulation was abolished in 2019, the TECs and Dansk Fjernvarme opposed that decision for fear that customers will choose other heating options (Dansk Fjernvarme, 2021; INT-14; INT-17). Until now, however, customers still seem to prefer DH connection over other options. So, the obligatory connection ability was important in Denmark, and especially for developing the DH sector. Reversely, the heat planning of municipalities and their ability to zone areas for certain heat options may also hamper TECs. Bjerringbrø, for example, was denied expansion to new areas around the 1980s, so that the municipality could expand a NG grid within the town.

Germany

In Germany, there municipalities are not obliged to plan heating in their areas, and they cannot be obliged due to existing laws (BMWi, 2020). Only the federal state of Baden-Württemberg has introduced compulsory heat planning (BMWi, 2020). Therefore, most municipalities in Germany act in accordance with their own discretion.

For TECs, collaboration with the municipality is key, as they depend on them for permissions and financing. Support from the local authorities, and especially the mayor, is an important part in the realization of a local DH system in Germany (Roesler & Hassler, 2019). For both cases, the local authorities and especially the mayor were involved with the project from the start. The mayors from both cases were widely respected within the local communities, and support from the mayor was important for increasing local acceptance. The motivations from the municipalities to support the DH system were self-sufficiency of the region and community cohesiveness.

Lathen was the initiative of a local farmer, the local bank, and the municipality, which were all represented in the project group of the TEC. The municipality was highly supportive from the beginning, and the interactions with the municipality were described by the TEC as a "good relationship". This support was mainly due to many citizens being dissatisfied at that moment with their current NG-supplier.

The idea for a DH system in Neuerkirch-Külz arose from a working group of the municipality to make their region more environmentally friendly. The municipality was the initiator from the start, and guided the project through development. As the municipality lacked the capacity and knowledge to develop the system, collaboration was sought with the regional utility company (responsible for e.g., water and waste disposal). In addition, the municipality created synergies with infrastructure construction by renewing underground utility infrastructure and sidewalks simultaneously, while also laying fiberglass to every house at no extra cost.

4.3. Results Part III: Application in the Netherlands

This section aims to answer the main research question:

> *What best practices from Denmark and Germany can be applied to overcome the systemic problems that Dutch thermal energy cooperatives have encountered?*

As summarized in Table 14 and further explained below, not all practices that have been identified in Section 4.2 can be applied to the Dutch context. For example, the Non-Profit principle (from Denmark) is an impossible intervention due to its large consequences, and the obligatory connection regulation (also from Denmark) does not fit the Dutch "free of choice" morale.

Table 14. Identified practices from Denmark and Germany that can be applied in the Netherlands to overcome the identified systemic barriers for TECs.

Systemic barriers	*Measures*	*Aimed at:*		*Found in:*	
		DH	*TECs*	*DEN*	*GER*
Regulatory barriers	Introduce standardized heating contracts	X	X	X	
	Introduce cost-based pricing	X	X	X	
Low legitimacy for TECs	Frame DH as low costs and high convenience	X	X	X	
	Embed the TEC in the local community		X		X
	Workshops and lectures aimed at increasing awareness of governmental organizations		X		X
	Increase lobby power by having one lobby organization		X	X	
Financing is crucial but difficult	Loans from public bank guaranteed by municipalities		X	X	X
	Subsidies from municipalities for TECs		X		X
Low professionality within TECs	One energy cooperative that operates multiple TECs		X		X
	Merge TECs to combine human capital		X	X	
Collaboration with municipalities	Introduce standardized methodology for municipalities	X		X	
	Introduce detailed technical catalogue	X		X	

4.3.1. Regulatory barriers

The overcome the *Regulatory barriers*, the national government may increase their control on the DH sector, which will also increase the ability of the Dutch ACM to monitor small-scale systems. Therefore, cost-based pricing and standardized heating contracts may be introduced, as seen in Denmark. The Dutch government has already announced its commitment to introduce a "more" cost-based methodology for heat prices as to increase transparency and protect consumers against the natural monopoly of DH companies. The details on the regulation for cost-based pricing are still unclear, although DH-prices will be decoupled from NG-prices for sure.

4.3.2. *Low legitimacy for TECs*

Currently, the rationale of Dutch TECs providing DH in the Netherlands is mostly around "good for the environment". Other aspects, such as high convenience and stable costs, are mostly neglected and have lower priority in their communication strategies. In Denmark, however, the focus is mostly on DH being a low-cost option for households, which provides higher convenience than individual heating solutions. By adopting that communication strategy, customers may become more aware and supportive regarding DH in general and therefore TECs. This means, however, that DH must have lower costs, otherwise TECs cannot communicate it. With the current NG-prices, however, DH definitely is a lower-cost option than heating from the NG-grid. Furthermore, embedding the TEC in the local community, by having local volunteers, events, and finding solutions to local problems, will increase the support of citizens towards TECs.

To increase awareness and trust of institutions and citizens regarding the cooperative model, TECs should be focused on increasing the awareness regarding the cooperative heating model. In Germany, they have used marketing campaigns to get rid of the "old-fashioned" image of cooperatives. This could be replicated in the Netherlands and can focus on organizing lectures and workshops to increase knowledge and awareness. This may be aimed at municipalities and the national government. Workshops and lectures specified on TECs are already being organized by Dutch actors, including Energie Samen, TKI Urban Energy, and the Participatiecoalitie. Those can build upon the Dutch cooperative history and expand the recent success of RECs into the field of DH.

Furthermore, increasing the lobby power of TECs is essential for increasing legitimacy and shaping regulations. As found in Denmark, TECs can lobby collectively within one organization (Dansk Fjernvarme) at governmental organizations, by initiating constructive conversations and creating sustainable relationships. The difference with the Dutch context, however, is that Dansk Fjernvarme represents 99% of all Danish heating companies, including municipal and private companies, while Energie Samen only represents energy cooperatives. Dansk Fjernvarme can represent cooperative, municipal, and private interests within the same organization because of their strict DH regulations, including the non-profit principle. Therefore, this practice is not completely applicable, but Energie Samen should continue to collectively lobby for only energy cooperatives.

4.3.3. *Financing is crucial but difficult*

To overcome the lack of financial capital in the development phase, the German TECs have both relied on funding from their municipalities. That funding, however, was voluntary, and depended on the municipality's willingness and financial power. The municipalities of the studied Dutch cases Ketelhuis and Muiderberg have already helped TECs by giving subsidies, but the municipalities of the other studied cases have not done this. Introducing the subsidies from the municipalities in the development phase might be an essential part to push the TECs to the next phase. This practice, however, requires knowledge and experience from municipalities in collaborating with TECs, which is further explained in Section 4.3.5.

Another municipal contribution to this problem is loans from public banks that are guaranteed by municipalities. Both Denmark and Germany have used this practice, which has shown to be effective. It has allowed TECs to receive loans with low interest rates (below 2%) and long payback times (up to 30 years) in both countries. The Danish public bank Kommunekredit does so in Denmark, while the German development bank (KfW) developed a specific program for renewable energies and also provides redemption grants. In the Netherlands there are two public banks, the BNG is an associative bank for all Dutch municipalities, while the NWB is a bank with special consideration for projects related to water and sustainability. Both banks are able to lend with payback times up to 30 years and interest rates below 2%. As of yet, no TECs have obtained a loan from them. By loaning to TECs with municipalities as guarantees, TECs can access more attractive loans and have more potential to get realized. Furthermore, this will reduce the heat prices of TECs customers due to the lower interest rates.

4.3.4. Low professionality within TECs

To overcome the low professionality within TECs in the Netherlands, an overarching energy cooperative that handles the daily operations of multiple TECs will be useful, as found in Germany. This will help TECs by combining human capital in the form of employees, knowledge, and experience, and may support with administrative tasks and operating the technical system. Furthermore, such an overarching energy cooperative may obtain the heat supply permit due to its higher professionalization. Energie Samen is an example of an energy cooperative that can take up such a task. The cooperative organization is already professionalizing with the aim to obtain a heat supply permit. INT-02 explains their plans for the future:

> *"In the future, the local energy cooperative will be supported by a regional energy cooperative, which provides administrative, financial, and technical support, so that the local energy cooperative can function properly."*

Adopting this practice alleviates TECs from their daily technical operations and administrative tasks but still allows TECs to operate according to the cooperative model.

4.3.5. Collaboration with municipalities

The TECs in both Denmark and Germany have benefitted from their good relationships with the municipality, which seem essential for Dutch TECs as well. Furthermore, the role of municipalities in Denmark, i.e., their responsibility for local heat planning, concurs with the role of Dutch municipalities, which have had to establish strategic heat plans themselves. In Denmark, a strong technical catalogue and a methodology was found to be key in the past for supporting municipalities and addressing their knowledge gap. The combination of the catalogue and the methodology has helped Danish municipalities in assessing the socio-economic costs of several heating options and choosing for the option with most benefits for society.

In the Netherlands, the national techno-economic model Vesta MAIS aims to serve that purpose. Vesta MAIS is a model to identify and compare potential heating technologies on system costs and emissions. Few shortcomings of the Vesta MAIs model were identified by Herreras Martínez et al. (2022). Those include a focus on still unavailable technologies and high complexity for municipalities with no programming skills. Moreover, the model only reports on average system costs and not end-user costs, while an insight on the range of costs is neglected. By introducing socio-economic costs to the model, as found in Denmark, municipalities are better able to assess the best heating options for neighborhoods. Furthermore, as municipalities already deal with a lack of experience and capacity, making the model simpler in usage seems beneficial.

5. Discussion

This section discusses the important findings of this research and compares them with existing literature. Then, the limitations of this research are presented, in combination with suggestions for further scientific research.

5.1. Theoretical implications

This research has used the socio-technical system perspective to identify systemic barriers that hamper Dutch TECs and discusses how similar problems have been addressed in other countries. Next to recent research by Fouladvand et al. (2022), this research is among the first to study TECs from a socio-technical system perspective. To the best of my knowledge, this research is the first study to solely focusing on TECs and researching case studies from three different countries. This research confirms the findings of Kooij et al. (2018), who found that the speed, direction, and success of energy cooperatives strongly depend on the institutional environment in which they develop.

The theoretical framework on systemic barriers developed by Mignon and Rüdinger (2016) was applied in this research. Using the theoretical framework has proved to be helpful in identifying systemic barriers in the Netherlands, and categorizing the systemic problems provided a clear direction for collecting relevant data. Therefore, the framework was modified to better reflect the results. The category '*Knowledge and interactions'* was expanded with three sub-categories: '*TEC and community*', '*Municipality*', and '*Other stakeholders'*.

The barriers around the financial infrastructure were identified within this study as one of the most important, to which multiple studies agree (Mignon & Rüdinger, 2016; Tarhan, 2015; Willis & Willis, 2012). The low financial capital from the start due to the grassroots nature, and high pre-investments for the development of DH production facilities and distribution networks provide a huge barrier. The high investments were also found to be a barrier for RECs in other contexts such as in Poland, Spain, and Turkey (Heras-Saizarbitoria et al., 2018; Kostecka-Jurczyk et al., 2022; Özgül et al., 2020). Furthermore, Dutch TECs were rarely able to access finance from a commercial bank at reasonable rates. A similar observation was made in the United Kingdom by Willis and Willis (2012). However, Danish, and German TECs can access long-term loans with low-interest rates. Johansen and Werner (2022) and Aumaitre et al. (2018) argue that access to long-term finance and low interest rates generally reduces investment risks for DH systems.

This research has shown that the hard and soft institutions are crucial for TECs. The regulatory framework in Denmark with the Non-Profit principle, cost-based tariffs and obligatory connections have led to an established and robust DH market with competitive prices. The competitiveness and transparency in the business models of TECs has generated the required acceptance among customers for DH systems. The strong cooperative history was also found to be of major importance for the Danish TECs, although the Netherlands and Germany also know a strong cooperative history. This is also found by Johansen and Werner (2022), who state that the mix of top-down and bottom-up support in Denmark results from their collective historical experiences, culture, and interchanging political and social rationales.

Within the Netherlands, the hard institutions seem to hamper the development of TECs as regulatory barriers have been identified. Although the aim of existing regulation is to protect consumers against the monopoly position of DH systems, the heat tariffs coupled to NG-prices and the market-based price setting have led to disproportionally high prices. Moreover, the lack of obligatory transparency in price setting affects trust of customers regarding DH systems in general. In Denmark, Gorroño-Albizu and De Godoy (2021) found that cooperative and municipal ownership lead to lower DH prices and higher transparency than commercial or state ownership. They also found that cost-based pricing in Sweden has led to companies being more open about their costs than market-based pricing. In addition, according to Roth et al. (2022), cost-based pricing for DH systems was found in Denmark and Estonia to secure low consumer prices. However, this is only true if the DH system owner has no interest in bypassing the regulation through legal and administrative practices. In Denmark, for example, private companies have circumvented cost-based pricing. Daughter companies purchased equipment and fuel from the mother company, and daughter company was lending from the mother company at high interest rates. To mitigate this possibility, Roth et al. (2022) found three practices for securing low consumer prices under private ownership regimes: 1) the regulation must be detailed and carefully implemented, 2) there must be access to data from all DH producers and distributors, and 3) independent authorities must monitor prices and delivery conditions. Without these requirements, private companies can circumvent the cost-based price regulation which leads to high consumer prices at those heating companies. Therefore, when implementing cost-based pricing for DH-systems, governments are recommended to take those three practices into account before implementation to decrease misusage by private companies.

A supportive political landscape at all levels for energy cooperatives is considered to be a deciding factor for their successful development (Tarhan, 2015). The initiation of the studied cases in Germany were found to be a direct consequence of the introduction of the feed-in compensation. This corresponds with findings from Roesler and Hassler (2019) and Klagge and Meister (2018) that the feed-in compensation had a positive influence on the formation of bioenergy villages. In addition, the findings of Wierling et al. (2018) resemble that the historic development of energy cooperatives often coincides with the development of financial support schemes at the national level, and especially feed-in tariffs. Although their findings relate to energy cooperatives involved in renewable energy and not DH systems.

Furthermore, some of the municipal regulations and procedures seem to be misaligned with regulations from the national government. For example, when the PAW program grants a subsidy to a TEC, the payment is first given to the municipality, after which the municipality was found unable to provide the subsidy to the TEC. The subsidy regulations of municipalities simply were not adjusted to handle such amounts of money. This resonates with the study on systemic barriers by Negro et al. (2012), who have found that misalignment of regulations can occur between different levels of government (e.g., between municipality and national government).

Regarding the soft institutions, low legitimacy for TECs was observed as an obstacle in the Netherlands and Germany. This same obstacle was found for energy cooperatives in Turkey, United Kingdom, and France, and is therefore likely to be an obstacle in general (Genus & Iskandarova, 2020; Mignon & Rüdinger, 2016; Özgül et al., 2020). For further development of TECs, attaining legitimacy is crucial, which has to be formed through conscious actions from various actors present within the system (Negro et al., 2012). The identified practices from

Denmark and Germany provide specific actions for application by Dutch actors and the national government. For instance, increasing the lobby power of TECs to influence regulations at the national level by acting collectively was found to be important by Dutch and Danish TECs within this research. This is also highlighted by Bergek et al. (2008), who state that it is important for actors within the socio-technical system to acquire political strength in order to influence regulations. Having legitimacy is a prerequisite for formation of a new socio-technical system, but also a result of that formation. Moreover, this study has found that the low number of established TECs in the Netherlands is a factor which currently affects the legitimacy for TECs. This is regarded as less of a problem for Dutch RECs, as there the number of cooperatives and public acceptance is continuing to grow (HIER & RVO, 2022; Oteman et al., 2017). Punt et al. (2022) showed that the number of successful RECs in Germany had a legitimizing effect in Germany for the development of TECs.

However, according to by Punt et al. (2022) and Martens (2022), legitimacy is primarily created on the local level. Provinces and municipalities, therefore, can foster energy cooperatives by local policies. According to Oteman et al. (2017) this was the case for Dutch RECs as well. Dutch RECs were focused on finding local legitimacy and developed largely outside of the political realm. Those findings suggest that TECs can lobby at local governmental organizations for shaping attractive local policies, although that was not identified within this study.

The municipality was found within this study to be one of the most important players for TECs in the Netherlands, Denmark, and Germany. This, because TECs depend on them for changes in the zoning plan, permits, and financing, which was also identified in previous studies (Hoppe et al., 2015; Klagge & Meister, 2018; Meister et al., 2020; Warbroek et al., 2019). Aumaitre et al. (2018) found another role of the municipality, one where they can create awareness within local communities about the benefits of DH systems, which will greatly increase the connection rate. Furthermore, this study found that the role of the municipality and thus their importance strongly depends on their capabilities. This was also supported by Warbroek et al. (2019) although they add that governance arrangements are as important. For example, in the Netherlands and Denmark, municipalities are required to do heat planning, while in Germany that is voluntary.

Furthermore, Meister et al. (2020) found that RECs in Germany and Switzerland benefit from the support of municipalities, and that municipalities can complement national regulations. Reversely, municipalities can benefit from collaborating with energy cooperatives as it gives them an additional instrument to implement municipal energy policy. In addition, Meister et al. (2020) found that when municipalities are a member of the cooperative, they provide more targeted support. Furthermore, Aumaitre et al. (2018) state that participation of the local and regional government within the local TEC is one of the key enablers. They can, for example, participate by connecting public buildings to the grid. This suggests that co-ownership of municipalities can be beneficial for both the municipality and the TEC, as it gives the municipality more control while the TEC may benefit from supportive local policy.

In addition, the capabilities of municipalities affect the financial arrangements that municipalities can provide to TECs, which was also found by Warbroek et al. (2019). Furthermore, this study found that some of the studied Dutch municipalities are lacking experience and capacity to deal with TECs. This is supported by research from Herreras Martínez et al. (2022), who found that many Dutch municipalities currently lack capacity for developing local heat plans. The authors further explain that municipalities are therefore depending on external expertise for heat planning. In addition, they found that the current data provided by the national government appears inadequate and suggest data standardization opportunities and more locally applicable instruments. That concurs with the practice in Denmark where having a standardized methodology and a detailed technical catalogue can help with improving experience of municipalities.

Finally, within Dutch TECs low professionality was identified, which often makes it difficult to collaborate with the municipality. Warbroek et al. (2019) found that the perceived trustworthiness of the TEC by the municipality influences their interaction. Other studies mention the lack of human capital at energy cooperatives in general (Herbes et al., 2021). To improve the professionality of TECs, the practices in Denmark and Germany of using an overarching energy cooperative to combine employees, knowledge, and experience were found applicable. Herbes et al. (2021) suggested a comparable approach in Germany for RECs but places emphasis on drawing on the support of commercial or municipal partners in the region. Support from commercial partners has been observed within the Netherlands, as the studied TECs Muiderberg and Panningen are both partnering with commercial companies in their search for technical expertise. Furthermore, Herbes et al. (2021) suggested establishing trainings and workshops for REC managers to overcome the lack of human capital.

5.2. Limitations and suggestions for further research

Several measures were applied to increase the reliability and validity of this research, as already stated within the methods (Section 3.4). However, some limitations were identified. First, this research is qualitative research with semi-structured interviews. This type of research method may contain biased information, as it includes opinions of a selected group of interviewees, and the interpretation of the researcher (Bryman, 2012; Elo & Kyngäs, 2008). The researcher has tried mitigating this bias as much as possible by comparing interview results with other sources and utilizing semi-structured interview guides and coding frameworks based on a theoretical framework. Furthermore, the researcher has made an effort to increase external reliability through using and sharing the interview guides and coding frameworks. However, as innovation systems change over time, future studies may yield different results (Negro et al., 2012).

Second, within multiple-case study design the criteria for selecting the cases is important (Yin, 2014). They should be selected so that they represent a wide range of cases as to increase external validity (Bryman, 2012). However, this research selected only one Dutch TEC that has been realized, leading to the identification of few systemic barriers within the realization phase. In addition, as the cases in Denmark are operating for years, little information was obtained in the Danish context regarding their development phase. Only five cooperatives were found to be in early phases of development in Denmark as of August 2022. The researcher has tried contacting them, but the TEC initiatives were not interested in an interview. Future research may examine international TECs that are still in the development phase, and Dutch TECs where the DH system has already been realized.

Third, the institutional context of Germany and the German TECs have been researched mainly through document analysis. Around 30 German individuals were approached, but the researcher has received almost no reaction. Therefore, two cases were identified with a large existing body of documents that that were realized recently. Future research may focus on deepening the results found for Germany by finding persons from German TECs that are willing to be interviewed.

Finally, this paper has focused on systemic barriers in the Dutch context and tested those on the Danish and German contexts. Therefore, not all systemic barriers in Denmark and Germany have been identified within this research, as the barriers in those countries were seen with the Dutch barriers in mind. Future research can utilize the adapted theoretical framework within this study to identify systemic factors instead of barriers for TECs in multiple countries to acquire a more complete international overview on systemic barriers. By comparing those systemic factors, interesting practices and measures from all countries can be identified which may be relevant to mitigate the Dutch systemic barriers.

6. Conclusion and recommendations

This section first answers the main research question and thereby indirectly the sub-questions. At the end, recommendations for accelerating the development of TECs in the Netherlands are given.

6.1. Conclusion

Energy cooperatives could play an important role in the adoption of DH systems in households, which could facilitate the achievement of our climate goals and decrease our dependency on fossil fuels. The aim of this study was to identify the systemic problems that Dutch TECs encounter and to find suitable solutions through researching the institutional context and case studies in Denmark and Germany. The main research question within this thesis was:

> *What best practices from Denmark and Germany can be applied to overcome the systemic problems that Dutch thermal energy cooperatives have encountered?*

Lending against low interest rates with long payback terms could help Dutch TECs in overcoming their lack of financial capital. This practice was found to be effective in both Denmark and Germany. There, the loans from public banks improve the business case of TECs and thus their potential to be realized. Dutch public banks BNG and NWB can adopt this responsibility, with municipalities or other governmental organizations guaranteeing.

Furthermore, municipalities in Germany were found to subsidize TECs. The TECs that were subsidized by their municipality in Germany have been realized, and those subsidies were important. Therefore, although some municipalities in the Netherlands are already subsidizing TECs, all municipalities could adopt the practice of supporting TECs through subsidies.

Standardized heat contracts and a cost-based pricing system in Denmark were found to be favorable for TECs. Those allow for only charging the necessary costs of DH systems. Also, higher transparency on the cost calculation is achieved. Moreover, standardized contracts allow for monitoring all small-scale systems. As the regulatory barriers in the Netherlands were found to be caused by the lack of transparency regulations, the standardized heating contracts and cost-based pricing system from Denmark could be applied.

In the Netherlands, municipalities are crucial as they have the directing role in the heat transition and TECs depend on them for local heat planning, permissions, and subsidies. Danish municipalities also have the responsibility for heat planning and are supported through a detailed technical catalogue and standardized methodology for overcoming a knowledge gap. This practice could be applied in the Netherlands to increase the expertise of municipalities in the heat transition. Therefore, the Vesta MAIS model from the Netherlands could be improved to include assessment on socio-economic costs and update the technical catalogue by only including available technologies.

Furthermore, TECs in the Netherlands find it difficult to acquire the heat supply permit. TECs in Denmark are merging into overarching and bigger organizations, to efficiently use each other's resources and create a larger pool of human capital. In Germany there are overarching energy cooperatives that have the capacity to operate multiple TECs. Both practices could be considered for the Dutch context to improve professionality of TECs. By having Energie Samen or other energy cooperatives operating smaller TECs, the required professionality could be realized.

The high number of successful TECs in Denmark and therefore the longer experience in developing cooperative DH projects have shown to be of high importance for increasing legitimacy for TECs. DH systems in Denmark are mainly being framed as a heating alternative with low costs and high convenience, while its environmental benefits are not neglected. Dutch TECs could focus more on the individual benefits of DH systems, such as low costs and high convenience, while pushing attention towards environmental benefits more to the background. This, because many TECs currently focus their communication strategy on the environmental benefits of DH systems. In addition, TEC initiatives in Germany obtained local legitimacy by embedding the TEC within the local community, by, for example, attracting local volunteers and solving local problems.

In addition, the collective lobby from Dansk Fjernvarme for better national regulations has helped to achieve high legitimacy in Denmark. This could be adopted in the Netherlands by letting Energies Samen continue to lobby for all energy cooperatives.

6.2. Recommendations for acceleration in the Netherlands

Policymakers are recommended to give TECs a stronger position in the heat transition and to align existing regulations and the upcoming heat law towards TECs. Three policy recommendations have been identified for policymakers from the practices in Denmark and Germany for accelerating development of Dutch TECs. First, implement standardized heating contracts to increase clarity and transparency and thus trust of consumers. This could indirectly benefit the ability of the ACM to monitor small-scale systems. Second, establish cost-based heat tariffs to improve transparency and trust of consumers. However, it is important, to introduce them carefully to mitigate the possibility of private companies in circumventing that regulation, as found by Roth et al. (2022). Before introducing cost-based pricing, it is recommended to have sufficient data from all DH producers and distributors available. Third, improve the national methodology VESTA Mais by reducing complexity of the system and report on socio-economic costs. This will support municipalities in their responsibility for local heat planning.

For public banks it is recommended to provide long-term low-interest loans for TECs and to allow municipalities to guarantee such loans. This is directed towards the bank of Dutch municipalities (BNG) and the Dutch bank of water boards (NWB). The national government is recommended to stimulate this role of the Dutch public banks. These loans will be highly beneficial for the business case of TECs and thereby helps them to overcome the lack of financial capital from the beginning. This will reduce the dependency of TECs on higher interest loans from commercial banks.

Organizations related to energy cooperatives, such as Energie Samen, are recommended to continue with increasing the awareness of governmental organizations and inform them about the important role TECs can play in the Dutch heat transition. This can be done through organizing workshops and lectures. It is recommended to build upon the strong cooperative history of the Netherlands and the high success rate of Dutch TECs. In addition, by collective lobbying governmental organizations, regulations can be shaped into supportive arrangements for TECs.

Municipalities are crucial for the development of TECs, while TECs provide municipalities the opportunity to implement a low-carbon heating system with public acceptance. Therefore, municipalities are recommended to take TEC initiatives seriously and support them continuously. Municipalities can help with, for example, acquiring financing and applying for permits.

For overcoming the lack of knowledge and expertise within a TEC, it is recommended to have one or multiple overarching energy cooperatives with the knowledge and expertise to support smaller TECs. As a consequence, the DH system can be operated professionally, while not being dependent on commercial companies. Energie Samen is in the perfect position to take this responsibility. Furthermore, Energie Samen is recommended to continue efforts for acquiring a heat supply permit, so that they can operate multiple TECs. This practice was found valuable in both Denmark and Germany, as it allowed to combine human capital.

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Appendix A – Interview guides

Interview guide – Dutch case studies	
Introduction	- Introducing myself; part of my master thesis in Sustainable Business and Innovation. - Explaining goal of the interview; to identify systemic barriers that you may or may have not experienced. - Ethical considerations; this interview is strictly confidential and everything you say will be handled anonymously. Do you agree with me recording the interview? This is purely for scientific purposes and the transcript will be removed when the research is done.
Start recording after consent	
1) Personal information	- Could you introduce yourself? (Expertise and function)
2) Introduction project	- Could you introduce the project? o Where? o Why? o Since when? o With whom? o Ambition? o Technical system? o Projected capacity? o Projected investment costs?
3) Financials	- How do you acquire financing? o Equity capital? o Debt? o Guarantees? o Subsidies?
4) Interactions	- What is the role of the municipality in your project? o How are the interactions? - What is the role of external advice companies in your project? o How are the interactions? - What is the role of the local community in your project? o How are the interactions? - What is the role of other TECs and/or Energie Samen in your project? o How are the interactions?
5) Barriers	- What has been the biggest barrier you have experienced within development? o Second biggest? o Third biggest? - Check if every dimension has been mentioned in the interview, if not, ask for that category: competition with commercial parties, financial infrastructure, knowledge infrastructure, regulations, legal forms, legitimacy, interactions with municipalities and other stakeholders.
Thank you!	- Thank you so much for your time and all the information you have given me! I appreciate it a lot!

Interview guide – Case studies in Denmark	
Introduction	- Introducing myself; this research is part of my master thesis in Sustainable Business and Innovation. - Explaining goal of the interview; to find solutions to identified systemic barriers in the Netherlands. - Ethical considerations; this interview is strictly confidential and everything you say will be handled anonymously. Do you agree with me recording the interview? This is purely for scientific purposes and the transcript will be removed when the research is done.
Start recording after consent	
1) Personal information	- Could you introduce yourself? (Expertise and function)
2) Introduction project	- Could you introduce the heating company? o Where? o Why? o Since when? o With whom? o Ambition? o Technical system? o Capacity? o Investment plans?
3) Financing in development difficult	- How do you acquire financing? o Equity capital? o Debt? o Guarantees? o Subsidies? - How may new companies acquire financing?
4) Interactions and capability municipality	- What is the role of the municipality with your heating company? o How are the interactions? - What responsibilities does the municipality have? o How does that advantage or disadvantage you?
5) Regulations unaligned	- What regulations are in place that directly or indirectly affect your company? o How do those affect you?
6) Unequal market competition	- Do you experience competition with commercial parties?
7) Professionalization and interactions	- Do you have all the required knowledge in-house? o If not, where do you acquire that? - What is the role of external advice companies in your heating company? o How are the interactions? - What is the role of other TECs and/or Dansk Fjernvarme in your heating company? o How are the interactions? - What is the role of the local community in your heating company? o How are the interactions?
8) Low legitimization	- How do you experience the reputation of DH in your area? o Are people satisfied?
Thank you!	- Thank you so much for your time and all the information you have given me! I appreciate it a lot!

Appendix B – Coding frameworks

Coding Framework – Part I: Dutch Systemic Barriers

CATEGORIES		SELECTIVE CODING	OPEN CODING
Market structure		Unequal market competition	Financial capital; Human capital; Lack of transparency bookkeeping; Established interactions of commercials; Low track record
Hard institutions		Unaligned regulations	Status Quo governance; Heat permit; Lack of sufficient legal form; Lack of transparency bookkeeping
		Unstable policies	Concept WCW unfavorable
Soft institutions		Low legitimacy	Low social legitimacy; Low technical legitimacy; Lack of track record; Bad reputation DH; Cooperative history
Financial infrastructure		Equity capital	Connection fee; Heat exchanger; Other
		Debt	Perceived risk; Payback time; Interest rate
		Guarantees	Willingness municipality; Ability regulations
		Subsidies	PAW; SDE; Other
		Finance in development	High risk; Wide variety of options; Dependent on local authorities
Physical infrastructure		No existing infrastructure	Large investments
Knowledge and interactions	TEC and community	Knowledge sharing	Energie Samen; Research programs; Interactions other TECs
		Energie Samen	Lobby power; Knowledge provider
		Community engagement	Existing community network; Social cohesion; Community identity
		Lack of professionality/human capital	Inexperience business case; Inexperience technical; Network; Project champions; Limited time availability
	Municipality	Inexperienced	Inexperience heat transition; Inexperience business case; Inexperience regulations
		Dependency TECs	Heat planning; Directing role; Permits; Financing
		Collaboration	Low capacity; Uncertainty around tasks; Slow workways; Employee continuity
	Other stakeholders	External knowledge	General; Legal; Technical; Financial;
		Stakeholders	External commercials; Housing corporations; Nature foundations; Water Authority
		Inexperience	Inexperience heat transition; Inexperience business case; Inexperience regulations; Inexperience TECs

Coding Framework – Part 2: Solutions

Denmark

CATEGORIES	SELECTIVE	OPEN CODING
Regulatory barriers	Standardized heating contracts	Transparency regulations; Standardized formats; Created by Dansk Fjernvarme
	Introduce cost-based pricing	Non-profit; Necessary costs; High trust of consumers
	Other	Highly regulated; National framework; Non-profit
Low legitimacy for TECs	Frame DH as low cost and high convenience	High trust of consumers; Low costs; High convenience; Stable prices; Environmental benefits
	Increase lobby power by having one lobby organization	Dansk Fjernvarme; Collective lobby; Different interests of heating companies
	Other	Legitimization; Cooperative history; No failures
Financing is crucial but difficult	Loans from public banks guaranteed by municipalities	Business case; Kommunekredit; Commercial loans; Low interest rates; Long-terms; Reduce investment risk
	Other	Subsidy (Fjernvarmepuljen); Non-profit; No competition
Low professionality within TECs	Merge TECs to combine human capital	Mergers; Acquisitions; To overcome lack of human capital; Grand challenges such as green transition and privacy; Low capacity within TECs
	Other	Big brother responsibility; Interactions other TECs; Dansk Fjernvarme;
Collaboration with municipalities is crucial but difficult	Introduce standardized methodology and detailed technical catalogue for municipalities	Lack of experience in the beginning; Larger experience; More expertise; Highest socio-economic costs; Assess socio-economic costs; All heating options; “Zoning”
	Other	Municipal heat planning; Obligatory connection;

Germany

CATEGORIES	SELECTIVE	OPEN CODING
Regulatory barriers	Other	No regulations for DH systems; No transparency regulations; Marktanreizprogramm; Renewable energy act; Feed-in compensation for biogas plants; No compulsory heat planning;
Low legitimacy for TECs	Embed the TEC within the local community	Community cohesiveness; Community discontent with NG-supplier; All initiators from the community; Local volunteers; Financed by local cooperative bank; Local farmers initiating the project; Support from mayor; Support from authorities;
	Increase awareness of governmental organizations through marketing	"Old-fashioned" image of cooperatives; Marketing campaigns; Lobbying at governmental organizations
	Other	Strong cooperative history
Financing is crucial but difficult	Loans from public bank guaranteed by municipalities	KfW loan and grant (guarantee); Low-interest; Long-term; Reduces investment risk; Improves business case
	Subsidies from municipalities for TECs	Feasibility from municipality; Connection subsidy from municipality
	Other	Subsidy from KfW
Low professionality within TECs	One energy cooperative that operates multiple TECs	Ownership; One energy cooperative operates multiple TECs; Lack of experience within TECs
	Other	Local expertise
Collaboration with municipalities is crucial but difficult	Other	Lack of experiences within municipalities; Regional utility company

Appendix C – Informed Consent Form

INFORMED CONSENT FORM for participation in:

Lessons from successful Renewable Heating Communities in Austria, Denmark, and Germany

I confirm that:

- I am satisfied with the received information about the research;
- I have been given opportunity to ask questions about the research and that any questions that have been risen have been answered satisfactorily;
- I had the opportunity to think carefully about participating in the study;
- I will give an honest answer to the questions asked.

I agree that:

- the data to be collected will be obtained and stored for scientific purposes;
- the collected, completely anonymous, research data can be shared and re-used by scientists to answer other research questions;
- video and/or audio recordings may also be used for scientific purposes;
- the video and/or audio recordings may be transcribed by an automatic transcription service.

I understand that:

- I have the right to withdraw my consent to use the data;
- I have the right to see the research report afterwards.

Name of participant: ________________________________

Signature: __________________________________ Date, place: ___ / ___ / ____, ___________

To be completed by the investigator:

I declare that I have explained the above mentioned participant what participation means and the reasons for data collection. I guarantee the privacy of the data.

Name:	_________________________
Date:	___ / ___ / _____(dd/mm/yyyy)
Signature:	