How to make citizens join district heating networks?

A qualitative study on citizens' barriers to join district heating networks and the potential strategies to overcome these barriers.

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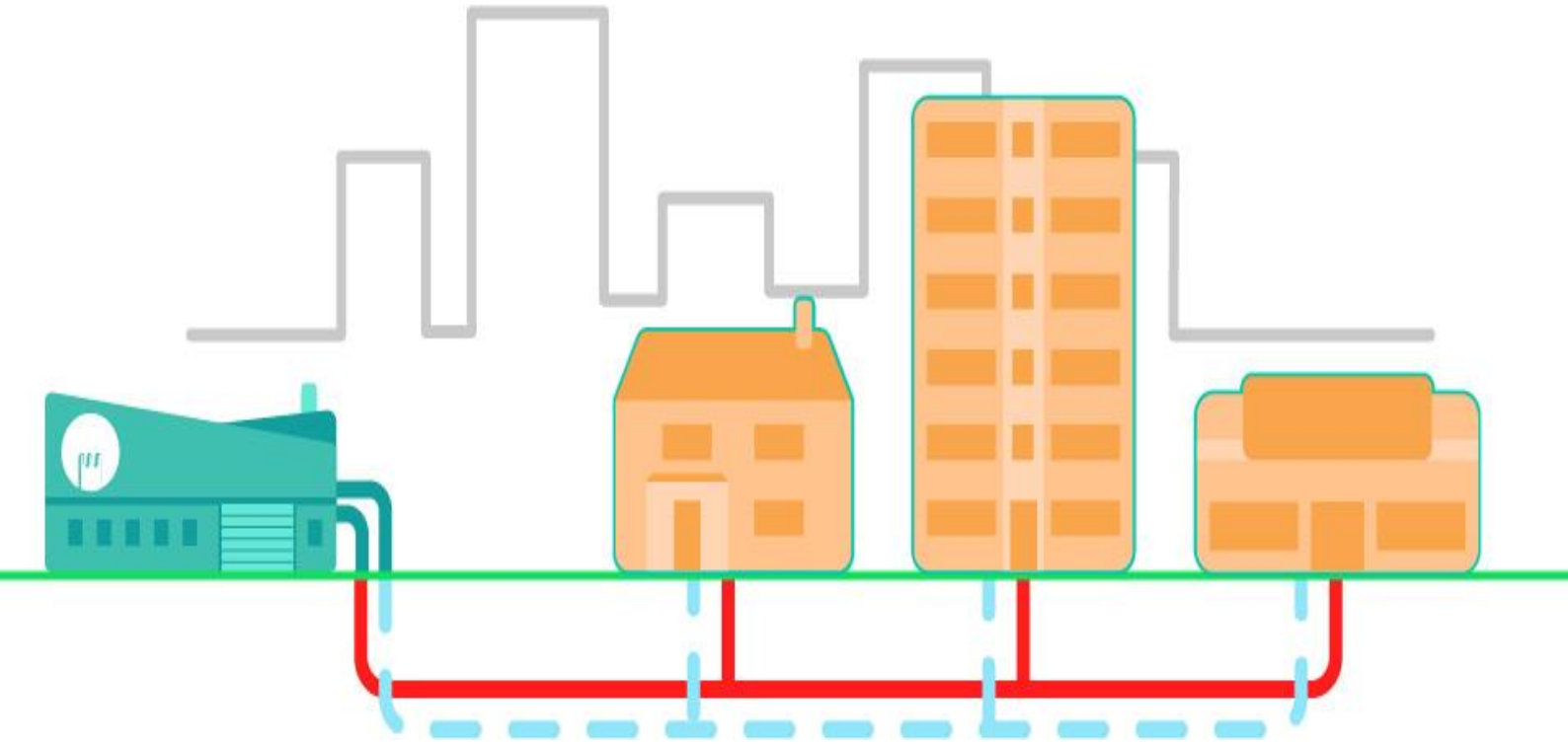

Colophon

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Abstract

District heating networks (DHNs) are an energy-efficient technology to generate heating while also reducing CO2 emissions. However, the Netherlands lags behind other European countries with DHNs because making citizens willing and able to join DHNs is difficult. Limited knowledge exists on citizens' barriers to join DHNs and potential strategies to overcome these barriers. To upscale Dutch DHNs, this study researches citizens' barriers to join DHNs and how these barriers potentially are overcome. Barriers and potential strategies were identified using literature- and desk research. Qualitative research aimed to further substantiate or nuance barriers and strategies identified. Theretofore, four Dutch DHN projects are studied based on nine semi-structured interviews and five additional expert interviews.

The literature study shows DHNs, like the energy transition, might affect citizens' comfort (indoors) and financial situation (risk of higher costs than potential benefits). Unlike the energy transition, DHNs might also affect citizens' trust. DHNs' barriers are divided into financial, trust and comfort barriers. The findings of this study largely confirm the barriers and strategies identified in the literature study. Homeowners only have financial barriers because they have to pay these costs (connection-, investment-, network- and lost investment costs). While housing corporations pay these costs for tenants. Trust (especially monopoly position and price transparency) and comfort (especially renovation, organise, electric cooking, heating and controllability) are barriers for tenants and homeowners. The main strategies, largely in line with the literature study, were citizens engagement, compensation, collectively paid network costs, large-scale DHNs, reducing renovation activities, non-profit DHNs, spreading network costs over a long period, citizen-owned DHN projects, experiencing indoor changes, unburdening and using social incentives. While strategies deducted from the interviews were that DHN suppliers or governments might sell boilers, lease boilers or buy second-hand boilers for homeowners.

This study suggests DHN projects potentially should use the strategies addressed above to make citizens willing and able to join DHNs. To make DHN projects able to do this, the national government might need to support DHN projects financially and legally. DHN projects might also focus more on emotional aspects (green neighbourhoods) rather than rational aspects (finance) to increase DHNs' social acceptance.

Keywords: District heating networks, Climate mitigation, Citizen participation, Energy transition, Sustainability, Monopoly position.

Index

1. Introduction

Greenhouse gases are released during the combustion of fossil fuels which amplifies the greenhouse effect. The amplified greenhouse effect leads to global warming, which causes climate change. Climate change reduces the livability on earth due to extreme weather conditions, flood risks, and water scarcity (EU, 2020). To mitigate the effects of climate change, the Netherlands has signed the Paris Agreement, in which they agreed to keep global warming below 2 degrees Celsius. This goal can be achieved by reducing greenhouse gas emissions (Rijksoverheid, 2020c).

Greenhouse gas emissions can be reduced in two manners. First, using sustainable renewable energy sources that do not produce CO2 and therefore do not amplify the greenhouse effect. Biomass, geothermal, solar, hydro, and wind energy are sustainable energy sources (Junejo et al., 2018). Secondly, increasing the efficiency of systems, meaning fewer fossil fuels are needed to create the same amount of energy as systems with low efficiency (Rosen et al., 2008). When dwellings are well-insulated fewer fossil fuels are needed to create the same thermal energy as poor-insulated dwellings, which lose much thermal energy.

In the Netherlands, several sectors emit greenhouse gases. In 2019, 31% of the total amount of greenhouse gases was emitted by the industry sector, 23% by the electricity sector, 19% by the mobility sector consisting of traffic and transport, 14% by the agricultural sector and 13% by the built environment sector (CBS, 2019). The built environment sector consists of households, but also companies and organisations that are categorised under the service sector (PBL, 2020). Figure 1 illustrates households emit 70% of the total amount of greenhouse gases in the built environment sector due to using gas to heat dwellings (CBS, 2019). Heating is the primary source of residential energy consumption, with 64% of the total energy consumption in the Netherlands (Eurostat, 2020). Thus, to significantly lower the emitted greenhouse gases in the built environment sector, households need to stop using gas to heat dwellings.

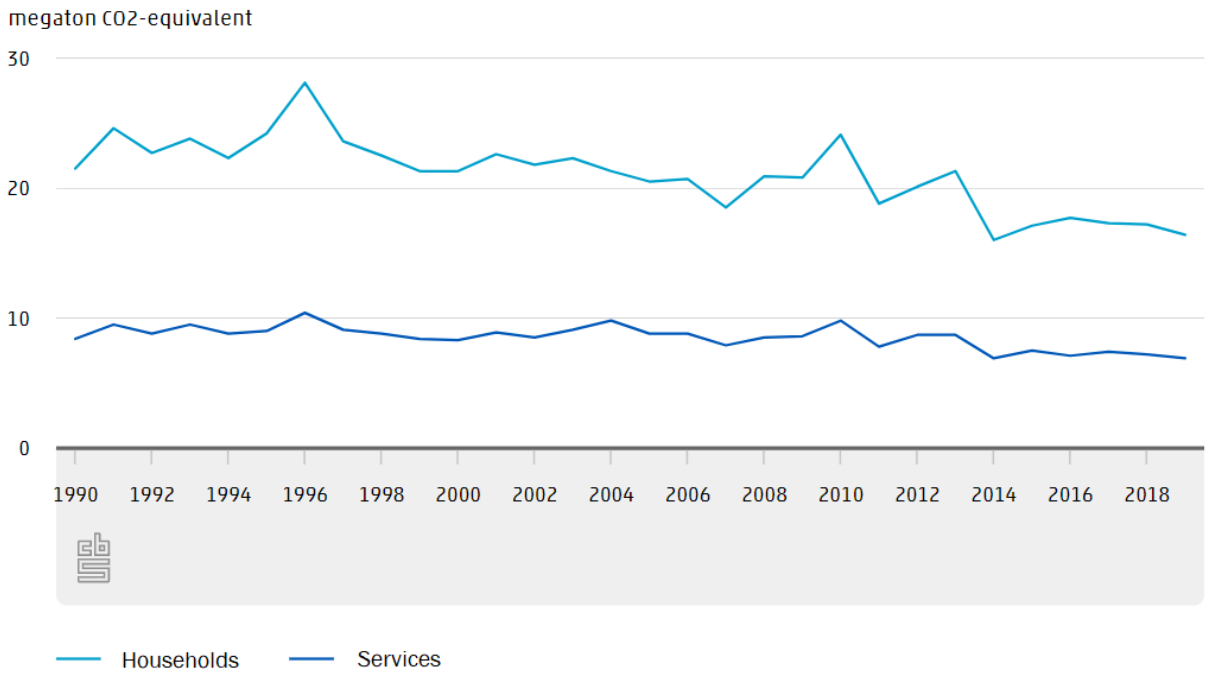

Figure 1: *Emitted greenhouse gases by the Dutch built environment sector* (CBS, 2019).

The Dutch national government aims for households to stop using gas by 2050 (Rijksoverheid, 2020a). This is a big challenge because the Netherlands is highly dependent on gas. Gas is used to heat approximately six million dwellings (Rijksoverheid, 2020d). Every year 200.000 dwellings need to switch to sustainable heating sources to make the goal achievable (Rijksoverheid, 2020a). Pilot projects called 'Aardgasvrije wijken' (natural gas-free districts) are subsidised by the national government and need to research sustainable heating opportunities (Rijksoverheid, 2020a). One of these pilot projects is situated in the neighbourhoods Paddepoel and Selwerd in the city of Groningen. The municipality of Groningen aims for all households to stop using gas by 2035. The municipality of Groningen has put the gas usage reduction in the city high on the agenda due to earthquakes. The extraction of gas leads to earthquakes in the Dutch province of Groningen, causing damage to many buildings (RTV Noord, 2020). To research the opportunities of sustainable heating, the municipality of Groningen develops in collaboration with the energy utility Warmtestad district heating networks (DHNs) in the neighbourhoods Selwerd and Paddepoel.

DHNs are collective networks of pipes transporting hot water to heat dwellings. This hot water is generated on a central location by using residual heat from, for instance, the industry or by sustainable produced heat. Sustainable produced heat is generated by, for example, geothermal heat and solar heating boilers. Fossil fuels are also used for heating. However, efficient DHNs use at least 50% sustainable heat or residual heat (European Commission, 2017). Eventually, the cooled off water from the dwellings is transported back to the central location. The gas system is organised differently. In the Netherlands, each dwelling connected to the gas network has a boiler. The boiler heats the dwelling by pumping hot water through the dwelling. In a DHN, the central location in which hot water is generated could be seen as a giant boiler. However, instead of heating a single dwelling, a DHN heats a district and uses sustainable or residual heat (Ancona et al., 2014). The number of connected dwellings is also an indicator if something is a DHN. DHNs provide heat for at least two buildings or building blocks. If a single building or building block is heated, it is called block heating (European Commission, 2017). DHNs are an important technology in the energy transition because DHNs are an energy-efficient way to generate heating for an area while also reducing CO2 emissions (Ancona et al., 2014; Joelsson & Gustavsson, 2009; Rezaie & Rosen, 2012). There are low-temperature DHNs (<50-60°C) and high-temperature DHNs (>60°C). Low-temperature DHNs are more favourable than high-temperature DHNs. With low-temperature DHNs, it is easier to implement renewable energy sources (Lund et al., 2014). However, low-temperature DHNs are potentially only successful when buildings lacking in energy-efficiency are renovated (Ziemele et al., 2018). Therefore, low-temperature DHNs are more challenging to implement than high-temperature DHNs. Furthermore, DHNs are most effective in densely populated urban areas due to the short distances between energy sources and consumers. Hereby, heat losses in the distribution are small. Figure 2 shows the percentage of residential heat supply from DHNs in European countries. DHNs are uncommon in the Netherlands because it has one of the lowest percentages of DHNs compared to other European countries. However, DHNs are not uncommon in other European countries since some countries have more than 40% of their residential heat supply from DHNs. Denmark is the frontrunner of DHNs with the highest percentage.

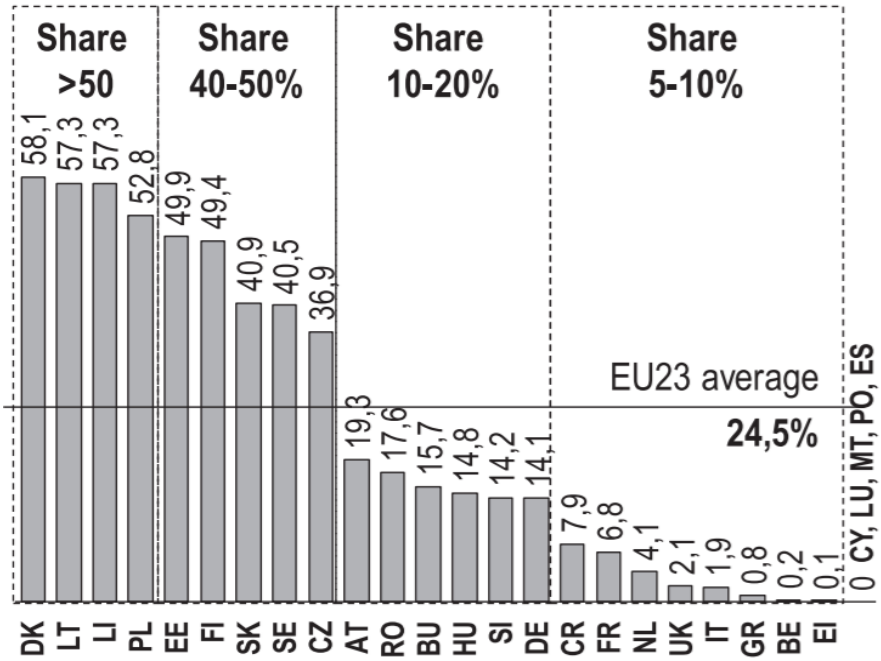

Figure 2: *Percentage of residential heat supply from DHNs in EU countries* (Sayegh et al., 2018).

The Netherlands lags behind, compared to other European countries, because municipalities struggle to realise DHNs on a large-scale. This is also the case in the DHN project in Paddepoel and Selwerd. DHN prices should potentially be lower than gas prices to make DHNs more appealing for citizens. Hereby, DHNs might be upscaled. However, making DHN prices lower than gas is often impossible because DHN suppliers need to pay DHNs' high network costs. Network costs consist of installation- and maintenance costs of the infrastructure. To make DHNs profitable for energy utilities, a part of the network costs is included in DHN prices (PBL, 2017). Due to the not more than usual (NMDA) principle, consumers are protected from high DHN prices by imposing that the maximum DHN price needs to be linked to the maximum gas price (Huygen et al., 2011). Therefore, DHN prices are equal to or slightly lower than gas prices (PBL, 2017). This is also the case in the DHN project in Selwerd and Paddepoel. Due to the small-scale of the project in Groningen (PBL. 2017), network costs are divided across a small group of consumers, increasing the DHN price for each citizen. Therefore, the DHN price for the DHN in Selwerd and Paddepoel is approximately equal to gas prices. This makes it potentially unappealing for citizens to join the DHN (PBL, 2017). Furthermore, DHNs are potentially not profitable on a small-scale because energy utilities have to pay a large share of the network costs. This is also the case in the DHN project in Paddepoel and Selwerd. DHNs could be profitable in Selwerd and Paddepoel because these are densely built-up areas due to the many high-rise buildings (Gemeente Groningen, 2020). Figure 3 shows the neighbourhood Selwerd. These types of high-rise buildings are seen everywhere in both neighbourhoods. However, due to the small-scale of the project (PBL, 2017), the energy utility Warmtestad can only include a small share of the network costs into the DHN price to prevent higher DHN prices than gas prices. This implies Warmtestad has to pay a large share of the network costs. Thus, DHNs potentially need to upscale because small-scale DHNs might not be profitable for energy utilities and upscaling DHNs probably make DHN prices lower than gas prices, potentially leading to a higher attractiveness for consumers to join DHNs.

Figure 3: *Neighbourhood Selwerd* (Google maps, 2021).

To upscale DHNs, Dutch more citizens need to join DHNs. However, making citizens willing and able to join is difficult. In various fields, Dutch DHN projects face challenges. In the economic field, questions arise about who needs to pay DHNs' network costs (Blom & Ahdour, 2017). Should network costs be divided over all DHNs' consumers, or should this be separated for each DHN project? In the field of law, questions arise about the effectiveness of laws and regulations (Schoots et al., 2017; Upham & Jones, 2012). Should the NMDA-principle be used to determine DHN prices, or are there other more effective pricing mechanisms? Should we give DHN suppliers a monopoly position, or should we allow competition? In the field of planning, questions arise about how DHNs could be made sustainable. Currently, DHNs are not fully sustainable. DHNs use, to some extend gas or coal for heating (Ekker, 2019). In the field of psychology, questions arise about how we can make citizens accept the discomforts they might get from joining DHNs. Citizens do not want their dwellings to be turned upside down for the installation (Hajer, 2020). All these challenges might influence citizens' willingness and ability to join DHNs.

A growing body of literature exists on how sustainable energy projects, such as wind farms and solar farms, can be realised, for instance, by increasing social acceptance (Wüstenhagen et al., 2007; Solangi et al., 2015; Janhunen et al., 2017). However, limited knowledge exists on how DHNs' challenges affect citizens to join DHNs and how to make citizens willing and able to join DHNs. In response to this knowledge gap, extensive research should be done on citizens' barriers to join DHNs and how to potentially overcome these barriers. Hereby, the number of citizens joining DHNs might increase, leading to upscaling DHN projects. Therefore, commissioned by Warmtestad, this study researches citizens' barriers to join DHNs and how these barriers might be overcome in the DHN project in Paddepoel and Selwerd, but also in other Dutch DHN projects. This study answers the following research question:

'What barriers influence citizens to join district heating networks and how might these potentially be overcome?'

This study focuses on how DHN projects can increase the demand for sustainable heat to upscale the projects. This might help to achieve the goals of the Dutch national government to make six million dwellings sustainable before 2050. The following sub-questions help to answer the research question:

1. What are the main risks citizens face and perceive when they join the energy transition in general, and how do these risks and their potential consequences inform barriers for citizens to join district heating networks?
2. What are barriers for citizens to join district heating networks?
3. What are potential strategies to overcome citizens' barriers to join district heating networks?

1.1 Reading guide

The first sub-question is an orientation on what challenges exist for the energy transition in general and how these challenges translate into barriers for DHNs. The challenges of the energy transition have already been extensively researched by researchers from several disciplines, such as (environmental) psychology, public administration and planning. Therefore, this sub-question is answered using literature research. The sub-question is answered in section 2.1. The second sub-question builds on these initial barriers and specifically targets barriers that occur for citizens to join DHNs. The third sub-question researches how the identified barriers might be overcome. Apart from a literature review to develop an initial list of suspected barriers and strategies, an empirical study into several cases is used. Desk research is also used to respond to these two questions from information sources, such as research reports, national governments letters, and media. Chapter 3 thoroughly explains the method. Chapter 4 answers sub-questions two and three. Chapter 5 gives the conclusion. Chapter 6 reflects on the research and chapter 7 reflects on the researcher's own process.

2. Theory

The energy transition could be challenging for citizens. It could change their environment due to highly visible windmills and solar panels with a large spatial footprint (Zuidema & Boer, 2018). Citizens could dislike the strong presence of renewable energy systems in their direct environment (Fisscher, 1995). The energy transition also instigates innovative techniques inside and close to citizens' dwellings, such as induction cookers, heat pumps, and electric driving. Citizens have to get used to these new techniques. Additionally, the energy transition will affect citizens' financial situation as investments in their dwellings are needed. Low-income households should not lag in the energy transition since this could lead to an increased risk of energy poverty or simply a growing inequality between various income groups regarding their reliance on clean energy. In this, energy poverty means citizens have insufficient access to crucial energy services. They do not have a healthy living environment because they cannot pay their energy bills and live in cold dwellings (Thomson et al., 2017). These risks could mean citizens feel overwhelmed by the energy transition. It is crucial to understand how citizens could join the energy transition and what these challenges entail for DHNs. Heat is a priority. It is the primary source of energy consumption in Dutch dwellings, with 64% of total energy consumption (Eurostat, 2020). Therefore, section 2.1 discusses potential risks of the energy transition for citizens and how these risks inform potential barriers for citizens to join DHNs. Afterwards, sections 2.2, 2.3 and 2.4 discusses the citizens' barriers to DHNs. Section 2.5 discusses the potential strategies to overcome the identified barriers. Section 2.6 presents all barriers and strategies in an analytical model which will guide the empirical study so as to further substantiate, nuance or enrich this model.

2.1 Citizens in the energy transition: key risks and considerations

The energy transition affects the lives of citizens in different ways. First, it affects their comfort. Dwellings need to be made energy-efficient by, for example, insulating and placing underfloor heating (Wang et al., 2009). These renovations increase citizens' comfort because citizens do not have to live in drafty dwellings with cold floors. However, citizens' comfort can also decrease. Extremely well-insulated dwellings can be poorly ventilated. The indoor air quality is poor due to fine dust in the dwelling. Fine dust increases cancer risks and is a potential cause of respiratory diseases (Nazaroff, 2013). Well-insulated dwellings also generally have a higher risk of overheating than poor-insulated dwellings on sweltering hot days (Pathan et al., 2008). Overheating could lead to deaths (Haines et al., 2007). Furthermore, it might be stressful to make dwellings sustainable because it is a drastic procedure. For example, dwellings are insulated, and solar panels are installed. Many people dread the hassle of making their dwellings more sustainable (BZK, 2019). Thus, the key comfort risks involving citizens in the energy transition are they can doubt that their comfort increases and can be overburdened.

Secondly, making dwellings sustainable also affects citizens' financial situation. They need to invest in their dwellings. Investing in renewable energy technologies, such as solar panels, leads to enormous upfront costs, and the investments are costly to reverse or irreversible. Moreover, investments are recouped in the long term (Bauner & Crago, 2015). The future benefits of the investments are uncertain due to changing regulations regarding renewable energy (PBL, 2020). Therefore, investment returns are uncertain for citizens. Furthermore, the investments are recouped by low energy bills, but fossil fuel prices fluctuate (PBL, 2020). Therefore, there is uncertainty about the financial benefits of using renewable energy over fossil fuels. However, investment costs of renewable energy technologies are declining (Steffen et al., 2020). Therefore, it becomes cheaper for citizens to invest in renewable energy technologies, and investments are recouped sooner. Besides, citizens can earn from the energy transition by selling surplus energy to the electricity grid (Green & Newman, 2017). Therefore, investing in renewable energy can have financial benefits for citizens. Thus, the key financial risk involving citizens in the energy transition is their doubt concerning financial benefits.

Third, the energy transition influences citizens' environment. The fossil fuel system is largely located under the ground. It is only visible on a few locations above ground where electricity is produced or fossil fuels are distributed, like gas stations. Renewable energy systems, such as wind and solar energy, are largely located above ground and are highly visible. They need large amounts of space to generate sufficient energy for society (Zuidema & Boer, 2018). Additionally, windmills can be noisy due to rotating blades (Butler, 2009). Therefore, renewable energy systems play a dominant role in citizens' living environment. Thus, the key environmental risk involving citizens in the energy transition is they could dislike renewable energy's presence in their living environment.

Citizens could resist renewable energy systems due to their strong presence in the living environment. Renewable energy systems are unwanted when they are sited close to where citizens personally live. This is called the Not In My Backyard (NIMBY) effect (Fisscher, 1995). Other citizens are willing to join the energy transition. These citizens start citizens initiatives, called grassroots organisations, that realise local sustainable energy projects, like wind and solar (Elzenga & Schwencke, 2015). Their motives are based on citizens' power, self-sufficiency, independence, and social cohesion (Schwencke, 2017).

Social acceptance should ideally be increased to reduce the number of citizens who resist renewable energy projects. To increase social acceptance, citizens participation is needed. Two aspects define citizens participation. The first aspect is citizens engage in the decision-making process. Citizens must perceive the planning process as fair. Thereby, citizens are more like to perceive decisions as fair (Gross, 2007; Lind et al., 1980; Folger, 1977; Barrett-Howard & Tyler, 1986; Tyler & Rasinski, 1991) and

trust in the decision-making authority increases (Gross, 2007; Tyler, 1989). For instance, citizens should be treated with respect (Gross, 2007; Tyler, 1989; Kitzmann & Emery, 1993), receive adequate information (Gross, 2007; Barrett-Howard & Tyler, 1986; Tyler & Griffin, 1991), have a degree of control over decisions (Tyler & Griffin, 1991; Kitzmann & Emery, 1993) and be heard (Gross, 2007; Tyler, 1987; Bies & Shapiro 1988; Leung & Li 1990). Engaging citizens results in higher social acceptance of renewable energy projects (Gross, 2007; Lauber, 1999). The second aspect is compensation, balancing costs and benefits of projects. Citizens can be compensated in different ways. For instance, communities get money from project owners, jobs are created through projects, or communities (partially) own renewable energy sources, leading to a cash flow towards communities (Río & Burguillo, 2009; Hvelplund et al., 2017; Olsen & Anker, 2014; Sovacool, 2013). Compensation might also make the energy transition acceptable because it potentially makes citizens able to join the energy transition. Providing compensation might increase social acceptance of renewable energy projects (Río & Burguillo, 2009; Kerr et al., 2017; Rudolph et al., 2018).

In short, the energy transition has potential negative and positive influences on citizens' comfort, financial situation and perception of the environment. Citizens respond in different ways to the energy transition's impact. Some join the energy transition by establishing grassroots organisations. Others resist the energy transition. However, citizens' perception of renewables might be positively influenced by increasing citizens participation in renewable energy projects (Gross, 2007; Lauber, 1999; Río & Burguillo, 2009; Kerr et al., 2017; Rudolph et al., 2018). Thus, the energy transition's comfort, financial and environmental aspects translate into potential risks for citizens to join the energy transition. However, citizens participation might increase social acceptance of the energy transition.

The key risks of the energy transition mentioned above manifest themselves in a couple of barriers to consider for DHNs. When zooming in on DHNs, it becomes clear environmental change is not the main issue. DHNs will impact the environment, but not as drastic as other sustainable energy technologies, like solar panels and windmills. DHNs are largely located under the ground. DHNs' installation can lead to temporary nuisance because roads partially need to be removed (Schilling et al., 2018). However, when DHNs are installed, people can use the road again without any physical changes to the environment. Therefore, the environmental changes are temporary. Similar to the energy transition, DHNs could affect citizens' comfort. Dwellings need to be turned upside down for the installation (Hajer, 2020). For example, gas installations might disappear. Therefore, residents need to switch to electric cooking (Schilling et al., 2018). Citizens could dread the hassle of making their dwellings more sustainable (BZK, 2019). Similar to the energy transition, the inside environmental changes might also affect citizens' financial situation because the renovation costs money. Furthermore, like the energy transition, social acceptance is needed to make more citizens join DHNs. Trust in the decision-making authority is needed to create social acceptance (Gross, 2007; Tyler, 1989). However, citizens often lack trust in DHN suppliers (Volkova et al., 2018). Therefore, DHNs might also affect citizens' trust

To conclude, the main risks for the energy transition, in general, are that it might affect citizens' comfort, financial situation, and perception of the environment. Social acceptance is needed to reduce the number of citizens resisting renewable energy projects. Similar to the energy transition, DHNs also might affect citizens' comfort and financial situation. The perception of the environment does not play a key role in DHNs. However, trust is another potential barrier for citizens to join DHNs because not just regarding the fairness of decision-making and information provision by the government, but also as citizens often lack trust in DHN suppliers (Volkova et al., 2018), decreasing social acceptance (Gross, 2007; Tyler, 1989). Therefore, potential barriers for citizens to join DHNs are divided into financial, comfort, and trust barriers. Table 1 in section 2.4 illustrates citizens' potential barriers to join DHNs.

2.2 Financial status of heat: collective or individual?

One of the potential main issues of DHNs are the costs. It is difficult for DHNs to compete with the gas system due to the gas system's path-dependency. In a path-dependency situation, developments are kept on the same path due to self-reinforcing forces. This makes it challenging to steer these developments from their current trajectory (Salet, 2018). Investments were made in the infrastructure of gas (Stein, 2017). These investments, for instance, the purchase of a boiler, are potentially lost when joining DHNs. Lost investment costs might make citizens unwilling to join DHNs.

Additionally, citizens do not pay for removing the gas connection (VEMW, 2021), but pay connection costs. Connection costs are the infrastructure from DHNs to dwellings and heat delivery sets inside dwellings. Heat delivery sets transfer heat to central heating systems, like radiators or underfloor heating. DHN consumers often rent heat delivery sets from DHN suppliers. Tenants will thus rent heat delivery sets, but do not pay more as they also pay a similar price for boilers in service costs. Building owners pay the infrastructure from the DHN to the dwellings (Schilling et al., 2020). Infrastructure costs might differ between DHN projects. The infrastructure costs depend on the number of connected dwellings and the amount of infrastructure needed. Therefore, economies of scale are essential. DHN projects in densely populated areas will lead to more customers, and the distance between dwellings and the DHNs are shorter. Thus, economies of scale might reduce infrastructure costs for connecting dwellings, but building owners still need to pay the costs. Additionally, DHN consumers need to rent the heat delivery set. The connection costs might demotivate citizens to join DHNs.

Furthermore, sustainable produced heat often has a lower temperature than heat produced by fossil fuel combustion (Schmidt et al., 2017). Therefore, dwellings connected to a DHN potentially need to be made energy-efficient to sufficiently heat them. Underfloor heating and insulation could make dwellings energy-sufficient (Wang et al., 2009). Citizens might also need to switch to electric cooking. These renovations will lead to investment costs (BZK, 2019). However, making dwellings sustainable does not provide enough financial benefits. The savings on the energy bill do not outweigh the costs (Schilder & Staak, 2020). Therefore, investment costs could make homeowners unwilling to join DHNs. Homeowners with low-income might also not afford these investment costs.

Tenants have lesser legal decision-making powers to make their dwellings sustainable than homeowners (Middlemiss et al., 2020). Landlords and housing corporations need to invest in renovating their rental homes (RVO, 2020c). However, 70% of tenants within a building unit of at least ten rental homes need to agree on connecting to a DHN (Rijksoverheid, 2021c). Therefore, it remains crucial for landlords and housing corporations to make tenants willing to join DHNs. Making rental homes sustainable can lower tenants' energy bills. Landlords and housing corporations can increase rent based on these savings. Hereby, they can (partially) finance the renovation of rental homes (Aedes, 2021b). Although tenants will mostly not face higher housing costs (NOS, 2020), the possible increasing rent could lead to scepticism of tenants thinking they will be worse off. This scepticism might be initiated by the bad image of housing corporations and landlords. They are not always positive in the news. Housing corporations and landlords are seen as being too much oriented on making profits (Hoogendoorn et al., 2006; Bremmer, 2020). Therefore, tenants might lack trust in housing corporations and landlords, making them unwilling to join DHNs, which might be an issue when connecting rental homes to DHNs.

Additionally, DHN prices are equal to or slightly lower than gas prices (PBL, 2017), making it for citizens potentially unattractive to join DHNs. DHN projects cannot easily lower their prices because the gas infrastructure is already established, and the DHN infrastructure is not. Therefore, the gas system only has maintenance costs, while DHNs have maintenance and construction costs (Bouw, 2016). These costs are the network costs. In some cases, DHN prices are lower than gas when projects have economies of scale, as many consumers are connected to DHNs. Thereby, network costs are

distributed over many consumers (Blom & Ahdour, 2017). Thus, DHN prices might decrease if a high percentage of citizens join DHNs. However, citizens might be unwilling to switch if DHN prices are equal to gas prices.

To break the vicious circle of equal DHN prices to gas prices, there is a discussion on how DHNs' costs should be borne. The discussion is about if DHNs' network costs should be paid collectively or individually. In the Netherlands, the individual consumer of a DHN project needs to pay that project's network costs. However, network costs are differently distributed for gas. Network costs of gas are paid collectively due to the socialisation of costs. Socialisation of costs means network costs are not paid by the individual consumer of a gas project, but all network costs are distributed among all gas consumers (Schilling et al., 2018; Blom & Ahdour, 2017). The bearing of network costs by individuals is known to constitute a potential barrier for the development and roll-out of DHNs:

First, each DHN has different network costs. The differences in network costs create inequality between citizens since some consumers have to pay less money than others in different areas (Schilling et al., 2018). Network costs potentially differ between areas due to economies of scale. In areas with a low population density, more infrastructure is needed to heat the same amount of dwellings as areas with a high population density. For example, the network costs in the city centre of Amsterdam are lower than in the village Loppersum. Therefore, the network costs of small-scale DHN projects could be less affordable for citizens, making them less attractive. Inequality of prices in different areas might be stopped when the costs are socialised because all DHN projects' network costs will be distributed among all DHN consumers.

Secondly, the DHNs' fixed network costs are a larger share of the total costs than variable consumption costs. This is the other way around for gas. Figure 4 shows how the costs of DHNs and gas are distributed. Consumption costs are the costs for consumers' actual energy used to heat their dwellings. Consumers with an economical consumption will have a higher energy bill when they join DHNs due to DHNs' high fixed network costs. Gas consumers can reduce their energy bill more by adapting their behaviour than DHN consumers due to higher consumption costs and lower fixed network costs (Hers et al., 2018). Therefore, DHNs' high fixed network costs might make it unappealing for citizens to join DHNs. In some DHN projects, the network costs are higher than in other DHN projects due to economies of scale. When DHNs are socialised, individual projects' costs potentially become more affordable because they are distributed among all DHN consumers (Schilling et al., 2018). However, to significantly lower DHNs' fixed network costs, the network costs should probably be distributed among all energy consumers because the amount of DHN consumers is small (Blom & Ahdour, 2017). When DHNs' network costs are lowered, consumption costs could become a larger share of the total DHN costs. Therefore, all DHN consumers can significantly reduce their energy bills by adapting their consumption behaviour, making it potentially more attractive for citizens to join DHNs.

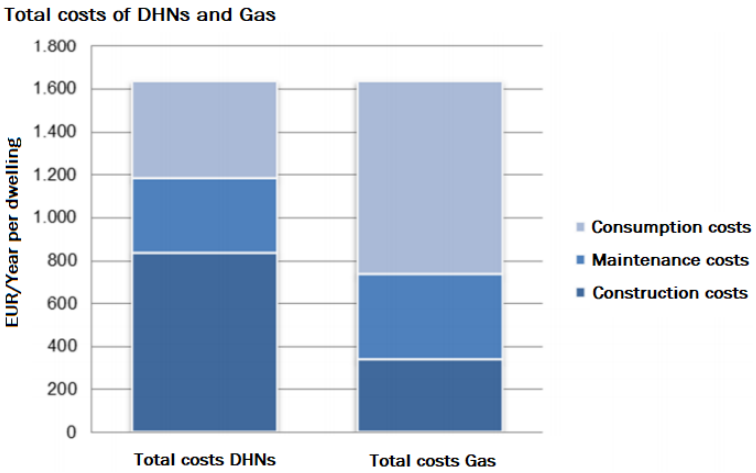

Figure 4: *Total costs of DHNs and Gas* (Ecorys, 2016).

Third, as mentioned earlier, DHN prices are equal to or slightly lower than gas prices (PBL, 2017), which makes it potentially unattractive to join DHNs. Lowering network costs might make DHN prices lower than gas prices. To significantly lower DHNs' network costs, DHNs' network costs should probably be distributed among all energy consumers (Blom & Ahdour, 2017).

To conclude, homeowners might lose investment costs and also have investment- and connection costs when joining DHNs. Furthermore, the individualisation of DHNs' network costs has three consequences. First, it might make small-scale DHN projects' network costs less affordable, making them less attractive. Secondly, consumers with an economical consumption might have higher energy bills when joining DHNs because fixed network costs are a larger share of the total costs than consumption costs. Third, DHN prices are equal to or slightly lower than gas prices (PBL, 2017), making it for citizens potentially unattractive to join DHNs. The issues with lost investment-, network-, connection- and investment costs might be barriers for citizens to join DHNs. Dividing the network costs of DHNs collectively over all energy consumers might be a potential strategy to reduce network costs. However, it is unknown if this is the best-suited strategy.

2.3 The consequences of DHNs on citizens' comfort

Although the financial barriers are among the crucial determinants of whether citizens are willing or able to join DHNs, comfort is another barrier that might reinforce citizens' unwillingness to join DHNs. Citizens' comfort may be reduced because the dwelling's renovation may cause nuisance. For instance, a connection to a DHN is made, which means pipes are placed in the front garden, and the boiler is removed. Citizens might not want their dwellings to be turned upside down for the renovation (Hajer, 2020). Another reason citizens' comfort may be reduced is citizens need to organise the connection to the DHN. They have to arrange many things, for instance, hiring construction workers, signing the contract with a DHN supplier, and planning the renovation. The loads of work could burden citizens and might make them less willing to join DHNs (BZK, 2019; Juwet, 2020).

Furthermore, citizens might perceive their comfort is not preserved when joining DHNs. This perception is visible in several key issues. First, citizens might assume DHNs will insufficiently heat their dwellings (Lidth de Jeude & Midden, 2014). Secondly, some DHN consumers assume they have limited control over the temperature because the water is already at a certain temperature (Lidth de Jeude & Midden, 2014). Third, citizens often need to switch to electric cooking since gas installations potentially disappear. However, citizens might dislike electric cooking (Lidth de Jeude & Midden, 2014; Koning et al., 2020). Citizens potentially assume electric cooking works less than cooking on gas (Koning et al., 2020). At last, well-insulated dwellings could lead to poor air quality and overheated dwellings (Nazaroff, 2013; Haines et al., 2007). The health risks or the fear of health risks might make citizens unwilling to insulate their dwellings. This is an issue because citizens with poor-insulated dwellings could potentially not join low-temperature DHNs since they might be insufficiently heated (Ziemele et al., 2018). The key issues, but also renovation nuisance, could worry citizens. It might be a fear of change.

Thus, citizens' comfort may be reduced because they have to organise the connection to the DHN and the renovation could cause nuisance. Citizens might also perceive their comfort is not preserved when joining DHNs. The issues mentioned might make citizens unwilling to join DHNs.

2.4 Distrust in DHN projects and the ambitions of Heat Law 2

Another issue is citizens often lack trust in DHN suppliers (Volkova et al., 2018). This might make citizens unwilling to join DHNs (Lygnerud, 2018). Four main reasons can be identified why citizens could lack trust:

First, there is a potential lack of transparency of DHN prices. The lack of transparency often jeopardises citizens' trust in DHNs (Li et al., 2015; Song et al., 2017). How DHN prices are constructed is often unclear for citizens, and they often cannot check the calculated price properly. Therefore, standardised bills with a breakdown of the prices are desirable (Which?, 2015). However, citizens might do not understand the metering systems of devices used in DHNs. For example, citizens do not know how the evaporation meters on radiators work (Bouw, 2016). Therefore, citizens can have difficulties checking the calculated prices because they do not understand the quantity of charged heat. This might result in a lack of transparency, increasing the number of complaints about DHNs (Li et al., 2015). If so, the reputation of DHNs is harmed and might reduce citizens' willingness to join DHNs. Another issue is citizens often cannot easily compare DHN prices with other heating alternatives (Bouw, 2016). Citizens might thus feel worse off with a DHN than with gas or other heating alternatives (Lidth de Jeude & Midden, 2014; Koning et al., 2020). Although the NMDA-principle ensures the DHN price equalises the gas price (Huygen et al., 2011), the NMDA-principle can also reinforce the negative perception of DHN prices. Currently, gas prices are increasing because of the higher taxes on gas. Due to the NMDA-principle, DHN prices increase as well (Wiebes, 2019). The result is citizens' might get a negative perception of DHN prices and become unwilling to join DHNs.

Secondly, competition and monopoly are the two primary forms of DHN market organisation. In a competitive DHN market, DHN suppliers need to compete with each other and other heat suppliers in the same area. The DHN price is not regulated because citizens can choose between multiple suppliers (Stennikov & Penkovskii, 2020). In a monopoly DHN market, DHN suppliers do not have to compete with other heat suppliers because it is the single supplier operating in an area. The government regulates DHN prices. The Netherlands has a monopoly DHN market. In a monopoly model, all heat supply aspects, including production, transportation, and heat selling, are organised by a DHN supplier. The DHN supplier also becomes the owner of heat sources and infrastructure of DHNs. The supplier is the single supplier in the heat market. Therefore, the supplier is a monopolist (Stennikov & Penkovskii, 2020). DHN suppliers' monopoly position potentially decreases citizens' trust (Hoogervorst, 2017). Citizens might question if private companies should be trusted and might subsequently fear private companies would be too profit-oriented (Upham & Jones, 2012). The result is citizens distrust they will pay a fair price for DHN heat (Which?, 2015). Furthermore, citizens can also fear a contractual lock-in in which they cannot join another heating alternative. Consequently, they might assume the arrangement starts with a reasonable price, but when citizens are connected to the DHN, the price increases, and citizens cannot join another heating alternative (Upham & Jones, 2012). Citizens typically want freedom of choice when choosing a supplier (Koning et al., 2020; Lidth de Jeude & Midden, 2014). Citizens' potential lack of trust in DHN suppliers' monopoly position might decrease citizens' willingness to join DHNs.

Third, the environmental impact of a heat supply might be an essential reason for citizens to join DHNs (Upham & Jones, 2012). Citizens from all social backgrounds consider sustainability a vital motive to switch (Suurs et al., 2019). However, Dutch DHNs are not fully sustainable. DHNs use, to some extent, fossil fuels to heat dwellings (Ekker, 2019). This information can raise suspicion among citizens because DHNs are depicted as sustainable heat sources. Therefore, citizens can feel like DHN suppliers are not transparent about their heat sources. This is problematic because citizens are often unwilling to commit to DHNs if they do not precisely know what DHNs entail (Upham & Jones, 2012).

Fourth, citizens might also distrust DHN suppliers can deliver certainty of supply. Such distrust relates to concerns about DHNs' technical reliability. For instance, citizens might wonder whether there will be no leaks in the system (Upham & Jones, 2012). Citizens often find certainty of supply crucial (Upham & Jones, 2012), and thus a potential lack of trust that DHNs can deliver certainty of supply is also a key potential barrier for DHNs to be socially endorsed.

To some extent, the Dutch government can force unwilling citizens to join DHNs or other sustainable alternatives. In 2018, a new law imposed that new dwellings cannot be connected to the gas system but should use sustainable options (RVO, 2020a). If other options are chosen in the development of new housing projects, citizens who live in new dwellings have to use the sustainable selected options. Currently, unwilling citizens cannot be forced by the government in another way. However, in 2022, the Environmental act (Omgevingswet) will enter into force. The Environmental act enables municipalities to force citizens to switch to sustainable options (Jager, 2019). This might again harm citizens' perception of DHNs. A lack of choice might result in resistance because citizens feel like their opinions are not heard (Dreijerink & Peuchen, 2019). Faced with such a risk, the government must try to make as many citizens as possible willing to join DHNs and assess options to make joining (financially) easier. In 2014, the Dutch Heat Law was established, protecting the consumer from DHN suppliers' monopoly position by implementing the NMDA-principle. In 2022, Dutch Heat Law 2 will be implemented to scale up DHNs and make them more sustainable (Wiebes, 2019). Heat Law 2 tries to tackle some of the barriers appointed above by focusing on three aspects:

First, tariff regulation is an aspect. The Minister of Economic Affairs and Climate (EAC) (2019) acknowledges the NMDA-principle is no longer sufficient in protecting consumers from DHNs' high costs due to the increased DHN prices, which are linked to higher gas prices. Therefore, Heat Law 2 no longer uses the principle. A new tariff method, cost-based, will be realised, so the consumer will not pay more than the efficient costs of a DHN. The tariff method gives insights into the actual DHNs' costs, stimulates efficiency by focusing on crucial cost-determining factors and determines the permitted financial return of DHN suppliers (Wiebes, 2019). The new tariff regulation could give citizens more clarity about how DHN prices are established and might decrease DHN prices since they are no longer linked to the gas price. Therefore, citizens' negative perceptions of DHN prices might diminish. The new tariff regulation might also increase citizens' trust in DHN suppliers because they understand suppliers cannot suddenly increase their prices.

Secondly, DHNs' sustainability is another aspect. The minister (EAC) aims to make all DHNs fully sustainable before 2050. In Heat Law 2, political instruments will impose DHN suppliers to invest in sustainable energy sources to reduce CO2 emissions cost-efficiently. This includes developing sustainable heat production and purchasing energy from other heat producers (Wiebes, 2019). This law might increase citizens' trust in DHNs' sustainability, making them more willing to join DHNs.

Third, certainty of supply is an aspect. DHNs are dependent on local energy sources. Therefore, certainty of supply is a vulnerable aspect of DHNs. The previous Heat Law focused on potential acute emergencies, while Heat Law 2 focusses on prevention. An example of prevention is DHN suppliers need to create a backup plan describing how to deal with imminent heat supply failures (Wiebes, 2019). The prevention measures might increase citizens' trust in DHNs' certainty of supply.

To conclude, Heat Law 2 tries to increase citizens' trust in DHNs' price transparency, monopoly position, sustainability and certainty of supply. However, it is unsure if these measures successfully tackle citizens' distrust. The first Heat Law imposed that DHN prices and gas prices should be equal, but citizens often still perceive DHNs as more expensive than gas (Lidth de Jeude & Midden, 2014; Koning et al., 2020). Therefore, it cannot be taken for granted that the measures are taken in Heat Law 2 help to overcome citizens' distrust in DHNs. Furthermore, Heat Law 2 does not fully tackle the lack of transparency on DHN prices because the law does not address how citizens can easily calculate their

DHN prices or compare it with other heating alternatives. The law also does not fully tackle citizens' distrust in DHN suppliers' monopoly position because it does not abolish the monopoly position of DHN suppliers. Due to the uncertainty, if Heat Law 2 will tackle citizens' distrust, it remains essential to research the barriers and how these can be overcome.

Table 1 gives an overview of the identified barriers discussed in the sections above. The following section discusses how Dutch and Danish DHN projects try to overcome the identified barriers.

Financial barriers	
Connection costs	Costs that homeowners, landlords, and housing corporations have when connecting a dwelling to a DHN.
Investment costs	Costs that homeowners, landlords, and housing corporations have when making their dwellings sustainable, for instance, installing insulation and placing underfloor heating.
Lost investment costs	Investments that homeowners, landlords, and housing corporations lose when joining DHNs, for instance, the purchase of a boiler.
Network costs	1. Different network costs for each DHN. The network costs of small-scale DHN projects might be less affordable for citizens, making small-scale DHNs potentially less attractive. 2. DHN prices can barely be reduced by adjusting consumption behaviour. 3. DHN prices equal to or slightly lower than gas prices, making it potentially unattractive for citizens to join DHNs.
Comfort barriers	
Heating	Assumption that DHNs insufficiently heat dwellings.
Controllability	Fear of lesser control over temperature.
Electric cooking	Electric cooking might be unwanted.
Renovation	Nuisance of dwellings' renovation.
Organise	Too much work to switch to DHNs.
Health	Worried about poor air quality and overheated dwellings due to well-insulated dwellings.
Trust barriers	
Price transparency	1. Lack of transparency about prices. 2. Difficult to compare DHN price with heating alternatives.
Monopoly	1. Lack of trust in monopoly position DHN suppliers. 2. No freedom of choice for a supplier.
Sustainability	Mistrust about DHNs' sustainability.
Certainty of supply	Lack of trust in DHNs' technical reliability.

Table 1: *Citizens' potential barriers to join DHNs.*

2.5 State of the art of Dutch and Danish DHN projects

This section researches how Dutch and Danish DHN projects currently trying to overcome the barriers illustrated in table 1. Danish DHN projects are researched since they are the frontrunners of DHNs in Europe (Sayegh et al., 2018). Therefore, a lot can be learned from Danish DHN projects on how to overcome citizens' barriers to join DHNs. The strategies used by Danish projects should be used as a guide for Dutch projects since it depends on the context of how strategies are developed and embedded. The broader social, political and economic context matters (Peck, 2011). Therefore, it is also crucial to understand how DHN projects in the Dutch context potentially overcome citizens' barriers. The barriers are categorised under financial, comfort and trust.

Potential strategies to overcome financial barriers

Financial barriers might well be the most important precondition. Some homeowners cannot afford to invest. Others might not want to invest. Connection- and investment costs might be vital reasons homeowners do not join DHNs. A dwelling might need to undergo much construction work, like insulating and placing underfloor heating (Wang et al., 2009). Thereby, investment costs can be high. Additionally, the costs of connecting dwellings to DHNs could be high depending on the infrastructure needed to connect dwellings to DHNs. High costs might make homeowners unwilling and unable to join DHNs.

The Dutch national government has made financing schemes to overcome connection- and investment costs. Homeowners can apply for the Sustainable Energy and Energy Savings (ISDE) subsidy to finance the connection to a DHN. The Dutch national government sets aside 100 million euros for the ISDE subsidy (RVO, 2021a). However, homeowners cannot get the subsidy to make their dwellings sustainable. Homeowners can loan money from the national government's heat fund to make their dwellings sustainable, for instance, insulation. Homeowners can lend a maximum of 25.000 euros with a low-interest rate. They can refund the money in a maximum of 20 years (RVO, 2020b). When costs are spread over a long time, monthly costs are significantly reduced. Therefore, the costs might be lesser-seen as large investments and are more affordable. This might increase homeowners' willingness and ability to pay investment costs. Additionally, homeowners can get a higher mortgage to pay for sustainable investments (Rijksoverheid, 2020b). Hereby, the costs are also spread over a long time. Homeowners can only get a higher mortgage when their joint income is a minimum of 33.000 euros (Rijksoverheid, 2020b). Therefore, this option is not accessible to low-income households. Furthermore, sustainable investments are recouped over a long time (Bauner & Crago, 2015). Therefore, a higher mortgage might not be attractive for citizens that move in a short time. A possible strategy to make more homeowners willing and able to invest is building-bound financing meaning loans are linked to dwellings. When homeowners move out, new homeowners pay the residual debt (BZK, 2019). This might be an attractive way for homeowners to invest in their dwellings. However, the Dutch national government has decided building-bound financing is too complicated to arrange legally and too expensive since banks cannot offer loans with low-interest rates (Winterman, 2020). Although building-bound financing is not used in the Netherlands, it remains a strategy to overcome investment costs. Thus, the Dutch national government created finance schemes to overcome connection costs, namely subsidy and investment costs, namely loans, increasing mortgage and building bound financing. However, the finance schemes might not be sufficient to overcome these barriers. The costs need to be recouped by a lower energy bill. However, the savings on energy bills do not outweigh the costs (Schilder & Staak, 2020). Therefore, it remains potentially unattractive for homeowners to invest in their dwellings. Homeowners might need more financial support to make them willing and able to pay for DHNs.

Dutch landlords and housing corporations need to pay the investment– and connection costs (RVO, 2020c). The national government offers the stimulation scheme gasless rental homes (SAH) subsidy to cover the connection- and indoor costs, namely 5.000 euros for each rental home. Indoor costs are, for instance, adjusting the fuse box and switching to electric cooking (RVO, 2021b). Additionally, the rental housing sector has to pay 9% VAT instead of 21% to place insulation, but they cannot get subsidies on insulation materials or underfloor heating (Belastingdienst, 2021). Housing corporations wanted to connect 100.000 rental homes to DHNs by 2022. However, this goal will not be achieved partly because it is too expensive to renovate rental homes (Hest & Duintjer Tebbens, 2021). Thus, potentially more financial support is needed to make landlords and housing corporations able to connect more rental homes to DHNs.

In Denmark, homeowners can also get a higher mortgage to pay for dwellings' sustainable renovations (Realkredit Danmark, 2021). Homeowners, landlords and housing corporations (building owners) can also get funding for dwellings' renovation. Danish building owners have to choose between two funding schemes. The first funding scheme, called 'Bygningspuljen', subsidises 30% of dwellings' insulation costs (SparEnergi.dk, 2021). There was great interest in the funding scheme since there were more than 18.000 applications. The entire budget, 33 million euros, has been used. Another 91 million euros now has been set aside (Energistyrelsen, 2021). The second funding scheme, called Håndværkerfradrag, subsidises the renovation services in dwellings, namely 20% of wages. The total subsidy is 3362 euros per person per year for the placement of underfloor heating and insulation. However, both funding schemes do not subsidise the connection costs (SparEnergi.dk, 2021). In short, the Netherlands has subsidies to stimulate building owners to connect their dwellings to DHNs, while Denmark has subsidies to stimulate building owners to renovate their dwellings. Both Dutch and Danish homeowners can increase their mortgage to finance the renovation, but only Dutch homeowners can get loans to finance the renovation. Thus, the Dutch and Danish financing schemes have some differences and similarities.

Another financial issue is the network costs. Dutch consumers pay network costs because they are included in the DHN price. **Section 2.2** discussed the issues of network costs. Small-scale DHN projects might have higher network costs than large-scale projects, making small-scale projects potentially less attractive. DHN consumers can barely reduce the DHN price by adjusting their consumption behaviour because fixed network costs are a larger share of DHN prices than variable consumption costs. Gas prices are also equal to or slightly lower than DHN prices (PBL, 2017), making it potentially unattractive to join DHNs. A possible strategy to solve these issues is to spread network costs over as many consumers as possible, which in an ideal case would essentially mean all Dutch energy consumers. In the ideal case, network costs potentially are equalized among all DHN consumers, become affordable for all DHN consumers, and are reduced since they are distributed among all energy consumers (Schilling et al., 2018). Additionally, the chance increases that the DHN price will be lower than the gas price since some costs are reduced (Blom & Ahdour, 2017). Thus, collectively paying network costs might make network costs affordable for every DHN consumer and overcome the network cost issues.

Danish DHN network costs also differ in each DHN area. The network costs are higher in small-scale DHNs than in large-scale DHNs due to economies of scale. Therefore, making DHNs large-scale might reduce network costs. Furthermore, different from Dutch DHN suppliers, all Danish DHN suppliers are non-profit. The DHN price for each project is determined by law. In general, DHN prices of the non-profit DHN suppliers are lower than other alternatives (Danish Energy Agency, 2017). Danish DHN network costs are low compared to Dutch DHNs since Danish DHNs are largely realised, and Dutch DHNs are not (Danish Energy Agency, 2017; Bouw, 2016). Therefore, Danish DHNs have mostly maintenance costs, while Dutch DHNs have maintenance and construction costs. The already realised Danish DHN infrastructure might reduce the DHN price and make it cheaper than alternatives. A possible strategy for Dutch DHN suppliers to lower network costs is spreading the network costs over

a long period, like long-term loans. Thus, network costs of Dutch DHNs might be reduced by making DHNs large-scale, making DHN suppliers non-profit and spreading network costs over a long period.

Furthermore, homeowners' lost investment costs, like purchasing a boiler, is another financial issue. In Denmark, municipalities can force homeowners to join DHNs when their boiler needs to be replaced (Danish Energy Agency, 2017). Building owners are obligated to purchase DHN heat delivery sets. However, they will not lose investment costs because they need to purchase heat delivery sets instead of new boilers (Patronen et al., 2017), which are approximately the same price (Installatie vakwinkel, 2021; CV totaal, 2021). Dutch homeowners are responsible for purchasing and maintaining boilers and will also not lose investment costs when their boiler needs to be replaced. They will rent heat delivery sets instead of purchasing new boilers (Kort et al., 2020). To conclude, homeowners will not lose investment costs if they join DHNs when their boiler needs to be replaced.

Potential strategies to overcome comfort barriers

Comfort is another barrier for citizens. Organising the connection to a DHN might strongly influence citizens' willingness to join DHNs because citizens often dread the hassle of making their dwellings more sustainable (BZK, 2019). Citizens might also be unable to organise the connection because they have no time or do not understand how to organise it. To overcome this issue, citizens potentially need to be unburdened (Juwet, 2020). Dutch and Danish parties try to unburden citizens who join DHNs by informing, advising and supporting them in dwellings' sustainable renovations and financing options (BZK, 2019; Vyver et al., 2020). Unburdening citizens by letting a party organise the dwellings' connection could also reduce the renovation nuisance. Construction work could be organised in a way residents have nuisance for a short time (SRUD, 2020). Thus, unburdening potentially overcomes issues with organising the connection to a DHN and renovation nuisance.

Other comfort issues are citizens might assume DHNs insufficiently heat dwellings and have lesser control over the temperature. Citizens might also dislike electric cooking and worry well-insulated dwellings will impact their health due to poor air quality and overheated dwellings. These issues, but also renovation nuisance, could worry citizens. It might be a fear of change, making them unwilling to join DHNs. In the 1920s and 1930s, the first DHNs were realised in Denmark. Currently, 64% of Danish households are connected to DHNs (Danish Energy Agency, 2021). Therefore, Danish citizens are probably used to DHNs. This might cause fear of change to be less of an issue in Denmark. In the Netherlands, DHNs are rare. Only 4,1% of Dutch households are connected to DHNs (Sayegh et al., 2018). Therefore, Dutch citizens are probably not used to DHNs. This might increase the fear of change.

Citizens participation might be essential to overcome the fear of change. Citizens might accept potential discomforts from joining DHNs when they are engaged in the planning process and treated fairly. For instance, communication was central to a project in Schiedam. People were available every day for questions from residents (Kort et al., 2020). Engaging citizens and fairly treating them could lead to greater legitimacy and trust in projects (Gross, 2007; Lauber, 1999). Furthermore, citizens might accept the discomforts when compensated (Río & Burguillo, 2009; Kerr et al., 2017; Rudolph et al., 2018). For instance, a Dutch DHN project in Amsterdam financially compensated residents of a flat when switching to electric cooking (Roos & Manussen, 2011). It is also essential to let citizens experience the indoor changes. Hereby, citizens can understand the changes do not affect their comfort. For instance, residents in the Dutch city Schiedam feared stir-frying is impossible on electricity. The DHN project organised cooking workshops to show residents stir-frying on electricity works well (Kort et al., 2020). Thus, citizens participation and letting citizens experience indoor changes might overcome citizens' potential fear of change.

Potential strategies to overcome trust barriers

Citizens' lack of trust in DHNs is another barrier discussed in section 2.4. Citizens might distrust DHNs' price transparency, monopoly position, certainty of supply and sustainability. The lack of trust could reduce citizens' willingness to join sustainable projects (Kalkbrenner & Roosen, 2016), such as DHNs. Trust issues can be at least partly overcome by engaging citizens in the planning process. Citizens engagement could increase trust (Gross, 2007; Tyler, 1989), when citizens perceive the planning process as fair (Gross, 2007; Lind et al., 1980; Folger, 1977; Barrett-Howard & Tyler, 1986; Tyler & Rasinski, 1991). They should, for instance, have a degree of control over decisions (Tyler & Griffin, 1991; Kitzmann & Emery, 1993) and receive adequate information (Gross, 2007; Barrett-Howard & Tyler, 1986; Tyler & Griffin, 1991). Some Dutch DHN projects try to engage citizens. For instance, the municipality in Arnhem allowed citizens to decide and explore possibilities for a DHN (Buitelaar & Heeger, 2018). Danish DHN projects do not engage citizens but create citizen-owned DHN suppliers. Approximately 340 are citizen-owned (Tian et al., 2019).

Citizen-owned DHN suppliers might increase citizens' trust in DHNs. There is a high risk that citizens do not trust private companies (Upham & Jones, 2012). Citizen-owned renewable energy systems make citizens more willing to join renewable energy projects (Kalkbrenner & Roosen, 2016). Local ownership is also more accepted than corporate (non-local) owned renewable energy sources (Hvelplund et al., 2017; Olsen & Anker, 2014; Sovacool, 2013). Citizens might trust their neighbours more than a private company. In Denmark, it rarely occurs DHN suppliers are fully owned by private companies (Huygen et al., 2019). The lack of private DHN suppliers is considered a factor that increases citizens' trust in Danish DHN suppliers. In the Netherlands, a few DHN suppliers are owned by citizens and municipalities. Large-scale DHN suppliers are private-owned (Schepers & Valkengoed, 2009). It is more affordable for Danish citizens to realise DHN suppliers than Dutch citizens. Danish DHN suppliers can borrow from banks at a low-interest rate, with municipalities guaranteeing them (Huygen et al., 2019). This reduces citizens' financial risks to establish DHN suppliers. Additionally, Danish DHN suppliers can buy heat from transport companies. Transport companies buy heat from heat production companies and transport it to DHN suppliers (Huygen et al., 2019). Hereby, DHN suppliers do not bear network costs. Dutch DHN suppliers are responsible for all heat supply aspects, including production, transportation, and heat selling (Stennikov & Penkovskii, 2020). These extra responsibilities lead to higher costs. For example, solar boiler fields need to be realised. Higher costs lead to higher financial risks and lower affordability as DHN suppliers have to borrow more money. The high costs reduce Dutch citizens' ability and willingness to establish DHN suppliers.

Dutch DHN suppliers have a monopoly position (Danish Energy Agency, 2020; Stennikov & Penkovskii, 2020). Citizens tend to lack trust in DHN suppliers' monopoly position (Hoogervorst, 2017). Citizens might fear they will not pay a fair price for DHNs and cannot switch to another supplier (Upham & Jones, 2012). They might also feel worse off with DHNs than gas or other heating alternatives (Lidth de Jeude & Midden, 2014; Koning et al., 2020). Dutch DHN prices cannot be higher than gas prices (Huygen et al., 2011). However, citizens may mistrust that DHN suppliers can still make a lot of profit. Danish DHN suppliers cannot make a profit. DHN tariffs are based on the costs (Tian et al., 2019). Therefore, Danish citizens are assured they will pay fair prices for heat.

To conclude, Dutch and Danish DHN projects use several strategies to overcome citizens' barriers. The financial barriers connection- and investment costs might be the vital reason homeowners are potentially unwilling and unable to join DHNs because these costs can be high. Dutch DHN projects try to overcome homeowners' connection costs by subsidies. Both Dutch and Danish homeowners could finance investment costs by increasing their mortgages. The Dutch government also offers loans to finance investment costs, while the Danish government offers subsidies. Additionally, building-bound financing could be a strategy to overcome investment costs. Another financial issue is DHNs' high network costs. Making projects large-scale, paying network costs collectively by as many consumers as possible, making DHN suppliers non-profit, and spreading network costs over a long period might

reduce network costs. Furthermore, citizens might not lose investment costs if they join DHNs when their boiler needs to be replaced.

Comfort is another barrier. Organising dwellings' connection to DHNs might strongly influence citizens' willingness and ability to join DHNs. To overcome this issue, Dutch and Danish parties try to unburden citizens by organising the connection to DHNs. Dwellings' renovation could also be organised in a way the nuisance is reduced. Other comfort issues are based on heating, electric cooking, controllability of temperature, and health risks. To potentially overcome these issues and renovations' nuisance, citizens' acceptability must be increased by letting them participate. Letting them experience indoor changes might also overcome these issues.

Citizens' potential lack of trust in DHNs is another barrier. Trust issues are based on DHN's price transparency, monopoly position, certainty of supply, and sustainability. Increasing citizens' trust might overcome these issues. Dutch DHN projects engage citizens, and Danish projects create citizens' ownership. Danish DHN projects also try to increase citizens' trust in DHNs' monopoly position and price transparency by making suppliers non-profit. The following section will present the analytical model in which all identified barriers and potential strategies are illustrated.

2.6 Analytical model

Literature and desk research is done to identify citizens' barriers to join DHNs. Afterwards, strategies are analysed to overcome these barriers. Table 2 illustrates the potential barriers and strategies. The barriers are categorised under financial, comfort, and trust barriers.

Financial barriers	**Strategies**
Connection costs	Governmental subsidies
Investment costs	Governmental loans Building-bound financing Increase mortgage
Lost investment costs	Replace broken boiler
Network costs	Collectively paid Non-profit DHN suppliers Large-scale DHN projects Spread network costs over a long period
Comfort barriers	**Strategies**
Heating	Citizens participation Experiencing
Controllability	Citizens participation Experiencing
Electric cooking	Citizens participation Experiencing
Health	Citizens participation Experiencing
Renovation	Citizens participation Unburdening
Organise	Unburdening
Trust barriers	**Strategies**
Price transparency	Citizens engagement Citizens ownership Non-profit
Monopoly	Citizens engagement Citizens ownership Non-profit
Sustainability	Citizens engagement Citizens ownership
Certainty of supply	Citizens engagement Citizens ownership

Table 2: *Analytical model.*

First, the **financial barriers**. *Connection costs* are costs building owners need to pay to connect dwellings to DHNs. *Governmental subsidies* might make connection costs affordable. *Investment costs* are costs for making dwellings sustainable. Building owners also pay them. *Governmental loans, increasing mortgages* and *building-bound financing* are potential strategies to make investment costs affordable. *Lost investment costs*, namely purchasing boilers, are potentially not lost when dwellings are connected to DHNs when *boilers need to be replaced. Network costs* are potentially higher for small-scale DHN projects than large-scale projects. DHNs' high fixed network costs make it potentially difficult to reduce DHN prices by adapting consumption behaviour, and DHNs are potentially unattractive due to equal DHN prices and gas prices. Making projects *large-scale*, *paying network costs collectively* by as many consumers as possible, making DHN suppliers *non-profit*, and *spreading network costs over a long period* might reduce network costs.

Secondly, the **comfort barriers.** Citizens might assume DHNs can insufficiently *heat* their dwellings and have lesser *control* over indoor temperatures. Citizens might dislike *electric cooking* and have nuisance of the dwellings' *renovation*. Citizens also might fear well-insulated dwellings might negatively impact their *health.* To overcome these issues, citizens' acceptability may be increased by letting *citizens participate* in the planning process. Heating, controllability, electric cooking and health issues might also be overcome by letting citizens *experience indoor change.* Additionally, citizens often dislike the hassle of *organising* the dwellings' connection to a DHN. Citizens might be *unburdened* by offering an organised service. Unburdening might also minimise the renovations' nuisance.

Third, **trust barriers**. Citizens might lack trust in DHNs' *price transparency* and *monopoly position.* Other issues are citizens might distrust DHNs' *certainty of supply* and *sustainability*. *Engaging citizens* in the planning process and *citizen-owned* DHN suppliers might increase citizens' trust. Additionally, *non-profit* DHN-suppliers might increase citizens' trust in DHNs' monopoly position and price transparency.

The following section discusses how the analytical model is used to conduct empirical research.

3. Method

This chapter elaborates on the research methods used for the study. This study uses literature research, desk research and semi-structured interviews as data collection techniques to answer the research question: "What barriers influence citizens to join district heating networks and how might these potentially be overcome?"

3.1 Desk research

In this study, literature and desk research are used to research citizens' barriers to join DHNs and potential strategies to overcome these barriers. The use of academic literature verifies what barriers and potential strategies are. However, there is limited academic knowledge on barriers and potential strategies. Therefore, desk research is used to get a holistic view. Desk research uses non-academic literature, for instance, reports and government documents (Weintraub, 2000). In the theoretical framework, sources such as media, reports from research institutes, government reports and national government letters are used. Although these sources are non-academic literature, the sources are still reliable since they exist of official sources, such as Rijksoverheid, while media sources are typically trusted newspapers, like the AD. Additionally, the sources exist out of independent research groups, like TNO and CE Delft. A holistic view is crucial to ensure no barriers and strategies were overlooked in the semi-structured interviews. The following section will elaborate on the use of semi-structured interviews.

3.2 Semi-structured interviews

A qualitative data method is used to do empirical research. A quantitative method can be used to generate more comprehensive knowledge from a larger population (Longhurst, 2010). Therefore, it is easier to draw conclusions for a larger population. However, the research question is a how question to get an in-depth understanding of citizens' barriers and potential strategies. A qualitative method allows the exploration of the experiences of heat experts and stakeholders of DHN projects on citizens' barriers and strategies. Researching four DHN projects instead of multiple DHN projects generates more in-depth knowledge (Longhurst, 2010). Additionally, with a qualitative data method, it is possible to highlight subjects and processes that cannot be deduced from surveys alone (Jonker & Pennink, 2004). Therefore, a survey conducted from several DHN projects might be insufficient in researching other barriers and strategies that were not found using literature and desk research. Furthermore, focus groups with residents from several neighbourhoods that need to join a DHN could be held. However, residents do not have the knowledge, like experts and stakeholders of DHN projects, on specific aspects of DHNs, such as collectively paying network costs. Therefore, they are less suited for answering questions arising from the theoretical framework.

Semi-structured interviews are used to answer the research question. Hereby, participants can formulate open answers and answers with "yes" or "no" were prevented. Semi-structured interviews can be a standalone research method and do not require an additional method (Longhurst, 2010). Semi-structured interviews with experts and stakeholders of DHN projects are used because they are fit to answer questions arising from the theoretical framework. It was possible to approach these participants through online communication technologies such as email and telephone.

The interviewer attempted to arrange two-hour interviews to question all identified barriers from the literature. However, it became evident most participants were only able to meet for an hour. Therefore, participants were asked to fill in a checklist before the meeting in which all identified barriers were questioned. The checklist is shown in appendix 1. The checklist is used as a guideline to question the most important barriers marked with 'strong' and 'very strong'. If there was time left, the interviewer also questioned barriers marked with 'neutral'. Barriers marked as 'little or no' and 'limited' were not questioned due to limited time. Therefore, it is unclear why and to what extent these barriers were framed as a barrier. Additionally, strategies that were not used by DHN projects or that

potentially overcome barriers marked with 'little or no' and 'limited' were not questioned due to limited time. Therefore, it is unclear if the strategies might be less useful for certain projects. If participants did not mention these barriers or strategies, there could only be said that apparently, these barriers or strategies were not important enough to mention. Furthermore, a structure is formed for the interview guide using barriers and strategies from the analytical model, shown in appendix 2. General questions and the energy transition in general question in the interview guide were not always questioned due to limited time. Although these questions are crucial for answering the overall research question, they were part of the literature and desk study focusing on the first sub-question, so as to give context in coming to an analytical framework. The interviews were held in Dutch since all the participants are Dutch. The interviews were also analysed in Dutch. Only the quotes used in the study are translated into English to avoid misinterpretation of the interviews.

3.3 Participant selection

Participant selection is crucial. Participants are mostly selected based on their experiences related to the research topic (Cameron, 2005). This study selected participants based on their experiences with DHNs. In total, fourteen participants were interviewed.

Five DHN experts were selected that had an overview of DHNs' developments in the Netherlands. Hereby, a general picture could be sketched of issues that influence DHNs' progress. Additionally, a general idea was given how DHNs and the national government try to solve these issues. No more than five experts were questioned, as this was not feasible in the research's time frame. The experts have different backgrounds to get still a holistic view of barriers and potential strategies used by DHN projects. Experts were selected from organisations working with DHNs, solving DHNs' issues, or studying DHNs. Table 3 shows the experts' organisations. The experts must have an overview of DHNs' developments. Therefore, experts were asked about their knowledge on the topic.

Organisations	Description
Expertise Centre Heat (ECW)	ECW is a knowledge centre for Dutch municipalities. ECW informs municipalities about technical, economical and sustainable aspects of the heat transition. The organisation is established by the Dutch Enterprise Agency (RVO) (ECW, 2021).
CE Delft	CE Delft is a research institute that contributes to a sustainable society with independent research and advice. CE Delft has economical, technical and policy expertise to inform governments and companies (CE Delft, 2021).
Regional Energy Strategy (RES)	RES is a governmental program that supports regions in the energy and heat transition. RES, for example, develops and shares knowledge, and connects parties (RES, 2021).
TNO	TNO is an independent research institute that studies different sectors, such as the energy transition and mobility (TNO, 2021).
Warming-Up	Warming-Up is a sustainable heat collective that creates applicable knowledge on heat systems (Warming-Up, 2021).

Table 3: *Experts' organisations.*

Four best practice cases were selected to get a deeper understanding of barriers and potential strategies. Best practices are DHN projects in which citizens were interested in or connected to a DHN. DHN projects that tried to connect homeowners of existing dwellings have the main focus of this study because, first, homeowners are the most challenging group to connect to DHNs. Every single homeowner needs to be willing and able to invest in their dwelling. Secondly, in existing dwellings, the gas connection first is removed, and then a connection is made to a DHN, while newly developed dwellings can be directly connected to a DHN. Therefore, it is cheaper to connect newly developed dwellings than existing dwellings. Thus, it is interesting to research existing dwellings because they are more complicated to connect than newly developed dwellings. Three best practices Overwhere-Zuid, Paddepoel-Noord and Bospolder-Tussendijken are researched that focus on connecting homeowners of existing dwellings. Table 4 shows why the cases are selected. Bospolder-Tussendijken did not yet

connect or make homeowners interested. The project is mainly chosen because it tries to connect tenants.

Best practices	Stakeholders	Description
Overwhere-Zuid Purmerend	Municipality of Purmerend Heat company: Stadsverwarming Purmerend Local initiative: Opgewekt in Purmerend	The project focused on 95 owner-occupied dwellings in the neighbourhood Overwhere-Zuid in Purmerend. Eventually, 85 owner-occupied dwellings are connected to the DHN (SRUD, 2020). It is an interesting project because not many DHN projects in the Netherlands succeeded to connect homeowners of existing dwellings.
Paddepoel-Noord Groningen	Local initiative: 050Buurtwarmte Local initiative: Grunneger Power Municipality of Groningen	The project was established by the local initiatives Grunneger Power and Paddepoel Energiek. They established the foundation 050 Buurtwarmte. The project focused on 450 owner-occupied dwellings in the neighbourhood Paddepoel-Noord in Groningen. Approximately 110 homeowners were interested in the project. However, the costs for each dwelling were high. The municipality wanted to upscale the project to make the costs more affordable (Middel, 2020). The project Paddepoel-Noord stayed in the initiation phase, and a new project was created, called Buurtwarmte. Owner-occupied dwellings in the neighbourhoods Selwerd, Paddepoel and Vinkhuizen, are the scope of the project. Buurtwarmte is established by Grunneger Power and the Municipality of Groningen. 050 Buurtwarmte no longer took part in the project (Middel, 2020). The Buurtwarmte project has just started in May 2021 (Gemeente Groningen, 2021). Paddepoel-Noord is an interesting project because not many DHN projects in the Netherlands have made a large number of homeowners of existing dwellings interested.
Bospolder-Tussendijken Rotterdam	Housing corporation: Havensteder Municipality of Rotterdam	The project focuses on 1.700 dwellings in the neighbourhoods Bospolder and Tussendijken in Rotterdam. The neighbourhoods consist of owner-occupied dwellings and rental homes (König, 2021). It is an interesting project because there are many low-income households. 72% of all households in Tussendijken and 70% in Bospolder are low-income households (Gemeente Rotterdam, 2020). Low-income households might not be able to afford to join the DHN.
Berkenflat Selwerd Groningen	Heat company: Warmtestad	The Berkenflat is located in the city of Groningen. It is owned by a housing corporation and will be connected to the DHN of Warmtestad. The tenants are elderly people. It is an interesting project because the tenants first resisted the project, but now more than 70% of the tenants approved (Dagblad van het Noorden, 2021).

Table 4: *Best practices.*

Tenants might be less challenging to connect to DHNs than homeowners because they potentially have lesser financial barriers. Landlords and housing corporations need to invest in rental homes (RVO, 2020c). However, landlords and housing corporations need to be willing and able to join DHNs. The willingness and ability of landlords and housing corporations are outside the research scope. This research focuses on citizens. Although tenants might have lesser financial barriers, they still might be unwilling to join DHNs. Housing corporations must make tenants willing to join DHNs because 70% of tenants within a building unit of at least ten rental homes need to agree on joining a DHN (Rijksoverheid, 2021c). Tenants of private housing are outside the research scope because the two studied best practices, Bospolder-Tussendijken and Berkenflat, try to connect tenants of a housing corporation to a DHN. In the first place, only Bospolder-Tussendijken would be studied. However, it became evident Bospolder-Tussendijken did not yet have the permission of tenants for the DHN, making the researcher unable to identify potential strategies to overcome tenants' barriers. Therefore, the Berkenflat was researched because the project does have the permission of tenants to connect to the DHN. Hereby, the researcher could identify potential strategies to overcome tenants' barriers. Table 4 shows why the cases are selected.

The researcher tried to interview stakeholders from different organisations within the best practices to understand citizens' barriers and potential strategies fully. The aim was to interview at least two stakeholders in each best practice. In the Berkenflat, a single stakeholder was interviewed because it

was an additional case to identify strategies. In total, nine stakeholders were interviewed from four best practices. Table 4 shows the interviewed stakeholders of each best practice. The stakeholders were asked if they were involved in the DHN project. Additionally, they were asked if they knew citizens' barriers and potential strategies. Hereby, it was made sure the participants were capable of answering questions. Stakeholders from citizens initiatives were interviewed to get the DHN users' perspectives. Stakeholders from the municipality and/or DHN supplier were interviewed to get the project managers' perspectives. Stakeholders from housing corporations were also interviewed to get the tenants' perspectives.

Warmtestad gave the researcher the contact details of potential participants. This enabled the researcher to reach the participants by telephone or email. In Overwhere-Zuid, stakeholders from the municipality, heat company and local initiative were interviewed. In Paddepoel-Noord, stakeholders from two local initiatives and the municipality were interviewed. There was no heat company involved in the project. In Bospolder-Tussendijken, stakeholders from the municipality and housing corporation were interviewed. The heat company could not be reached, and there was no local initiative active in the project. In the Berkenflat, the heat company was interviewed because it played an important role in making tenants willing to join the DHN.

Before the interview, the researcher used desk research to familiarise herself with the cases and the participants' contributions in organisations and cases. Furthermore, interviews should be conducted in an informal and quiet place to make interviewees and the interviewer comfortable (Longhurst, 2010). Therefore, the interviews were conducted at the organisations' locations. The interviewer and interviewees kept 1,5 meters distance to adhere to Covid-19 measures. If interviewees were not comfortable meeting physically, the interviews were conducted through Google meet.

3.4 Data analysis

The interviews were only recorded with participants' consent. Therefore, the focus could be on the conversation instead of taking notes (Valentine, 1997). The recordings were transcribed. To analyse the interviews, codes are added to the text using the computer program ATLAS.ti (Seers, 2012). ATLAS.ti is a tool to test expected relations between concepts and the data obtained (Dey, 1993). The codes are derived from the literature (deductive) and the interviews themselves (inductive) (Fereday & Muir-Cochrane, 2006). The code tree is shown in appendix 3.

3.5 Ethics

There was no power relationship between the researcher and participants. The study did not impact participants since the interview questions did not contain sensitive material. However, it should be clear to participants that the data was handled confidentially and who has access to the data (Hay, 2010). This is done by protecting the data with a password on the computer. The data itself has only been shared with the supervisor. The outcomes of the data will be shared with the supervisor and Warmtestad. The interviewees will be displayed anonymously to ensure the data outcomes can also be shared with other parties. The names of the participants are only shared with the supervisor. If the study were to be repeated, a researcher can request these names from the supervisor and question the participants again if they approve. Organisations' and projects' names will be mentioned in the research to understand participants' expertise and DHN projects' characteristics. With the participants' consent, participants' functions will also be shared with other parties. Participants were able to comment on their quotes used in the research before 10-07-2021. Participants had the right to stop the interview at any time (Longhurst, 2010). Before the interview, this information was presented to the participants, and a consent form, shown in appendix 4, was signed by the participants and researcher. In this form, the ethical aspects of conducting the research are included.

4. Results

4.1 Participants' characteristics

Tables 5 and 6 show information about the participants. The function of six of the fourteen participants is not given because the participants did not want to be traceable or did not respond to the question of whether their function may be mentioned. Additionally, the participants will be kept anonymous. Therefore, each participant has a pseudonym. The results of the interviews are discussed and compared with the literature. In some cases, the housing corporation Havensteder did not answer. When this is the case, the text will show that thirteen participants have responded instead of fourteen. Section 4.2 discusses citizens' barriers to join DHNs, and section 4.3 discusses the potential strategies to overcome citizens' barriers.

Organisation	Function	Pseudonyms
Expertise Centre Heat (ECW)	Expert of heat supply	ECW
CE Delft	Researcher sustainable cities	CE Delft
Regional Energy Strategy (RES)	-	RES
TNO	Researcher heat supply	TNO
Warming-Up	-	Warming-Up

Table 5: *Experts' characteristics.*

Organisation	Function	Pseudonyms
Overwhere-Zuid Purmerend		
Municipality of Purmerend	Program manager sustainability	MuPu
Heat company: Stadsverwarming Purmerend	Project manager	SVP
Local initiative: Opgewekt in Purmerend	-	OiP
Paddepoel-Noord Groningen		
Local initiative: 050Buurtwarmte	Project team member communication	050Buurtwarmte
Local initiative: Grunneger Power	-	Grunneger Power
Municipality of Groningen	Project manager energy transition	MuGro
Bospolder-Tussendijken Rotterdam		
Housing corporation: Havensteder	-	Havensteder
Municipality of Rotterdam	-	MuRo
Berkenflat Selwerd Groningen		
Heat company: Warmtestad	Advisor residents affairs	Warmtestad

Table 6: *Stakeholders' characteristics.*

4.2 Citizens' barriers to join district heating networks

This section will discuss the differences and similarities between barriers of homeowners and tenants to join DHNs. The barriers are categorised under financial, trust and comfort.

Financial barriers

The financial barriers are shown in table 7. Connection- and investment costs might be the vital reason homeowners do not join DHNs because these costs can be high. Eight out of thirteen participants mention homeowners are unwilling or unable to join DHNs because connection costs are higher than the purchase of a boiler. Three other participants of Overwhere-Zuid argue connection costs might be no barrier when homeowners are compensated. This is mentioned in 4.3. Warming-Up did not know if connection costs are a barrier. Furthermore, ten of the thirteen participants mention investment costs are extra costs homeowners do not have when keeping gas, making them potentially unwilling or unable to switch. Only RES and MuPu argue investment costs might be no barrier if DHN projects reduce renovation activities. This is mentioned in 4.3. Warmtestad argues connection- and investment costs are no barrier for tenants because the housing corporation pays these costs. A lower energy bill cannot recoup connection- and investment costs because DHN prices are equal to or slightly lower than gas prices (PBL, 2017). The costs might be recouped in the future if DHN prices are unlinked with gas prices and DHNs become cheaper. Additionally, making dwellings sustainable is financially unattractive for homeowners because the savings on the energy bill do not outweigh the costs (Schilder & Staak, 2020). Two participants mention investments cannot be recouped. Overall, the respondents thus indicate DHNs are considered financially unattractive or too expensive for homeowners to switch. ECW explains why connection costs are a barrier for homeowners, OiP explains why some homeowners are unable to pay investment costs, and 050Buurwarmte explains why investments cannot be recouped:

> *''People are satisfied with a boiler. In the worst case, replacing a boiler will cost you between 1.500 and 2.000 euros. You can use a new boiler for ten years. [When joining a DHN] you have to pay connection costs. In new buildings, the connection costs are between 3.000 and 5.000 euros. Connecting existing buildings will cost heat companies more. Therefore, they probably will ask for more [money]. […] This is already more costs than purchasing a new boiler.'' (ECW)*

> *''If you want to properly insulate a dwelling, […] you need to replace all glass in a dwelling with double or triple glass. You also need to insulate floors, the roof, and cavity walls. […] The costs are approximately 30.000 euros. That is a lot of money. […] People that do not have money […] cannot afford these costs.'' (OiP)*

> *''People who [sustainably] invest in their dwelling do this for themselves because their dwelling does not increase in value. You actually lose money.'' (050Buurtwarmte)*

Lost investment costs are also a potential strong barrier for homeowners. Investments were made in the infrastructure of gas (Stein, 2017). These investments are potentially lost when joining DHNs. Eleven out of fourteen participants mention replacing boilers with heat delivery sets is a potential barrier for homeowners if the boiler is still new. Therefore, it depends on the boiler's age if lost investment costs are a possible strong or limited barrier. Havensteder and Warmtestad mention lost investment costs are no barrier for tenants. The next paragraph elaborates on this. TNO did not mention lost investment costs. RES explains why lost investment costs could be a barrier:

> *''It is unfortunate when you just invested in a new boiler that costs 1.500 euros, and after a year, the municipality wants to construct a DHN. I would also say […] that I want to have 1.400 euros from the municipality because I could only use my boiler for a year.'' (RES)*

The costs mentioned above are only barriers for homeowners because homeowners pay these costs, and tenants do not. Landlords and housing corporations need to invest in renovating their rental homes (RVO, 2020c). Tenants will rent the heat delivery set (Schilling et al., 2020). The housing corporations in the projects Berkenflat and Bospolder-Tussendijken finance the connection- and investment costs. The housing corporations also buy the heat delivery set. Therefore, tenants do not have to rent the heat delivery set. Network costs could affect the energy bill. Tenants and homeowners have to pay the energy bill. However, as noted in 2.2, tenants do not face higher housing costs (Aedes, 2021b). Therefore, tenants will not be worse off with DHNs. However, tenants could be sceptic about DHN prices. Section 'trust barriers' will discuss this lack of trust. The network costs barrier has three aspects:

First, DHN prices are equal to or slightly lower than gas prices (PBL, 2017). Six of the fourteen participants mention the equal DHN price to the gas price makes it less attractive for homeowners to join DHNs. Other participants did not mention the equality between DHN and gas prices. DHN prices are not higher than gas prices due to the NMDA-principle (Huygen et al., 2011). Therefore, it does not make citizens strongly unwilling or unable to join DHNs. However, it is a strong barrier when linked to recouping investment- and connection costs because with equal prices these costs might not be recouped. CE Delft explains why it is difficult to stimulate homeowners to join DHNs due to DHN prices:

> *''Without an [financial] opportunity, it will be challenging to stimulate homeowners to join DHNs. It will help if a DHN is more favourable than the current situation.'' (CE Delft)*

Secondly, DHN prices can barely be reduced by adjusting consumption behaviour because DHNs' fixed network costs are a larger share of the total costs than variable consumption costs (Hers et al., 2018). Four of the fourteen participants mention consuming economically or making a dwelling sustainable can barely reduce the energy bill. Three other participants mention it potentially is no barrier because citizens often do not understand fixed and variable costs. Other participants did not mention high fixed network costs. Thus, high fixed network costs might be no barrier but further aggravates the risk that it is impossible to recoup the investment costs in a reasonable term. MuGro explains why high fixed network costs are an issue:

> *''[High fixed network cost] are a strong barrier for homeowners who made their dwellings sustainable. They will lose money because of it. You want to avoid that. After all, you want to ensure that people who make their dwellings sustainable save more costs than people who do not make their dwellings sustainable. So it is very inconvenient how those tariffs are constructed.'' (MuGro)*

Third, network costs could differ for each DHN project (Schilling et al., 2018). Two participants argue different network costs within a city could make citizens unwilling to join DHNs. Other participants did not mention different network costs. Only CE Delft states network costs might only slightly differ. Therefore, differences in network costs are potentially no barrier.

Financial barriers	Barriers for homeowners	Impact of barrier
Connection costs	Extra costs paid by homeowners to connect a dwelling to a DHN. Includes the connection of the dwelling to the DHN and the heat-delivery set.	Strong
Investment costs	Extra costs paid by homeowners for making their dwellings sustainable. For instance, insulation and underfloor heating.	Strong
Lost investment costs	Lost costs due to purchase of a boiler.	Limited/Strong
Network costs: DHN price equal to gas price	Network costs are the maintenance and construction costs of the DHN infrastructure. The gas price is equal to the DHN price. Therefore, homeowners might not be able to recoup their investment- and connection costs.	Strong
High fixed network costs	DHN prices can barely be reduced by adjusting consumption behaviour. This potentially makes homeowners unwilling and unable to make their dwellings sustainable.	No barrier, but aggravates
Unequal network costs	Network costs could differ between projects.	No barrier

Table 7: *Financial barriers and their impact.*

Trust barriers

The trust barriers are shown in table 8. DHN suppliers' monopoly position potentially strongly influences citizens' willingness to join DHNs. Citizens might fear they will pay an unfair price (Which?, 2015) and cannot switch to another supplier (Upham & Jones, 2012). All thirteen participants argue citizens often lack trust in DHN suppliers' monopoly position and dislike having no freedom of choice when connected to a DHN. Two participants explain why a monopoly might be a barrier for citizens:

> *''People say: ''I do not believe that these are the prices. [..] When we are your customer, you [050Buurtwarmte] will increase the prices because you are a monopoly.'' Thus, it is actually a trust barrier instead of a financial barrier. The fear of not being able to choose is really strong. That [fear of no choice] has come up on all residents evenings.'' (050Buurtwarmte)*

> *''Tenants are stuck to one organisation [when joining DHNs]. They assume the organisation can just double the prices next year.'' (Warmtestad)*

Price transparency also might strongly influence homeowners' and tenants' willingness to join DHNs. It is often unclear for citizens how DHN prices are constructed and if calculated prices are correct (Which?, 2015). Citizens might also not easily compare the DHN price with other heating alternatives (Bouw, 2016). Citizens might thus feel worse off with a DHN than with other heating alternatives (Lidth de Jeude & Midden, 2014; Koning et al., 2020). Thirteen of the fourteen participants mention citizens risk not understanding calculated DHN prices and feel they will pay too much. Only MuPu argues prices are transparent when citizens are engaged. This is mentioned in 4.3. Eleven of the fourteen participants mention DHN prices often cannot easily be compared with gas prices. Therefore, citizens might feel worse off with DHNs than gas. Only SVP argues DHN prices can be compared with gas prices when citizens are engaged. This is mentioned in 4.3. Only Warmtestad argues tenants might not have an interest in comparing DHN prices with gas prices. They only want to know the DHN price. Havensteder did not mention comparing prices. Although tenants might have lesser interest in comparing prices, price transparency remains a strong barrier for tenants and homeowners. Two participants argue why citizens feel worse off with DHNs:

> *''The tariffs are structured differently. People hear stories, and people do not understand them. It is difficult to explain how tariffs are established. And people are just suspicious. They think they are being deceived.'' (MuGro)*

> *''People thought their energy bill would increase when switching from gas to a DHN. If you compare your gas bill with a DHN bill, you can see a difference. Cubic Gas versus Gigajoule. It is difficult to explain to people the DHN bill includes all costs, while the gas bill does not include maintenance and purchase costs. If you include those costs, the costs are similar.'' (MuPu)*

Additionally, no choice between heating alternatives potentially is a limited barrier. Citizens might dislike they cannot choose between other heating alternatives. Projects already decide DHNs are the best solution without discussing them with citizens. When citizens do not have a degree of control over decision-making, citizens might perceive the project as unfair, leading to a lower acceptance (Tyler & Griffin, 1991; Kitzmann & Emery, 1993). Warming-Up and MuPu mention no choice between heating options might make citizens unwilling to join DHNs. Warming-Up explains why it leads to lower acceptance:

> *''If people expect they will have little influence on the choices made for a natural gas-free solution in their neighbourhood, this predicts a low acceptance of the natural gas-free solution.'' (Warming-Up)*

However, citizens may be unwilling to join DHNs due to poor communication from the DHN project, rather than having no choice between heating alternatives. Citizens possibly have lower acceptance because they are inadequately informed (Gross, 2007; Barrett-Howard & Tyler, 1986; Tyler & Griffin, 1991). Four other participants mention DHN projects poorly communicate with citizens about DHNs. Therefore, they are potentially less willing to join DHNs. Other participants did not mention no choice between heating alternatives. OiP explains citizens of Overwhere-Zuid were overwhelmed by the DHN project because it was suddenly communicated through a newspaper.

Furthermore, the sustainability of DHNs is potentially a limited barrier for citizens. The environmental impact of a heat supply can be an essential reason for citizens to join DHNs (Upham & Jones, 2012). Therefore, if DHNs are not (fully) sustainable, citizens might be unwilling to join DHNs. Ten of the fourteen participants indicate citizens might have suspicions about DHNs' sustainability. Therefore, they might not want to join DHNs. For instance, citizens question if biomass is sustainable. However, eight of the ten and three other participants argue most citizens are not concerned with sustainability. Sustainability is not something that keeps citizens busy. It does not affect them personally. Sustainability is potentially a limited barrier because only two of the ten participants argue most citizens are concerned with DHNs' sustainability, and the other eight mention most citizens are not concerned. Another participant did not mention DHNs' sustainability. 050Buurtwarmte explains why DHNs' sustainability might influence citizens' willingness to switch:

> *''Biomass is very negative in the news, while many DHNs use biomass or want to use it. Thus, the public opinion is that many DHNs are not sustainable. […] I think people want to feel they are doing the right thing by using a truly green alternative. As soon as there are any doubts about DHNs' sustainability, this negatively impacts the projects.'' (050Buurtwarmte)*

Certainty of supply might also be a limited barrier for citizens. Citizens might be concerned about DHNs' technical reliability (Upham & Jones, 2012; Lidth de Jeude & Midden, 2014). Four of the fourteen participants argue citizens might not trust DHNs' technical reliability because it is an unknown technique. Eight other participants did not mention certainty of supply, and two participants did not know if it is a barrier. Certainty of supply is potentially a limited barrier since only four of the fourteen participants mention it. Warmtestad argues what citizens might think of certainty of supply:

> *''It [certainty of supply] was not the most crucial aspect. However, people were thinking about […] what would happen if the power plant falls out? In that sense, they felt like a guinea pig.'' (Warmtestad)*

Trust barriers	Barriers for homeowners and tenants	Impact of barrier
Monopoly position	Citizens often fear that DHN suppliers can suddenly increase their prices and they cannot choose another supplier.	Strong
Price transparency	Citizens often do not understand the construction of DHN prices and cannot easily compare DHN prices with heating alternatives. They might feel worse off with DHNs.	Strong
No choice between heating options	Citizens might dislike they cannot choose between heating options.	Limited
Sustainability	Potential mistrust about DHNs' sustainability.	Limited
Certainty of Supply	Potential lack of trust in DHNs' technical reliability.	Limited

Table 8: *Trust barriers and their impact.*

Comfort barriers

Comfort barriers, shown in table 9, could potentially influence homeowners and tenants willingness to join DHNs. Renovation nuisance is potentially a strong barrier because the renovation cannot be prevented. Citizens might not want their dwellings to be turned upside down for the renovation (Hajer, 2020). Eleven of the fourteen participants argue citizens often dislike the renovation in their dwellings, making them potentially less willing to join DHNs. Two other participants argue the renovation might be no barrier if citizens are engaged and unburdened. This is mentioned in 4.3. Another participant did not mention renovation nuisance. Two participants explain why citizens might dislike the renovation:

> *''It [renovation] is a hassle for people. Especially placing underfloor heating because […] you need to remove all your stuff from the floor. […] Similar to insulating your roof. If your entire attic is full of junk, you need to clear it out first. Otherwise, the workers cannot reach it. Furthermore, citizens have their boiler in the attic. With a DHN, you need a heat exchanger. This replaces the boiler. Therefore, you need to place all kinds of pipes inside dwellings to the attics.'' (TNO)*

> *''Renovation activities in someone's dwelling, in someone's personal space, is always intense and invasive. Three until five days, strange people come inside tenant's dwellings. That is pretty intense.'' (Havensteder)*

Organising the connection to a DHN is also a potentially strong barrier for citizens. Citizens have to arrange many things, which could burden citizens (BZK, 2019; Juwet, 2020). Nine of the fourteen participants argue citizens might think organising the connection to a DHN is a hassle or might not understand how to organise it. For instance, they do not know how to arrange subsidies or sign contracts with DHN suppliers. Four other participants argue organising the connection might be no barrier if citizens are unburdened. This is mentioned in 4.3. Another participant did not mention organising the connection. Two participants explain why citizens are potentially unwilling or unable to organise the connection:

> *''It depends on how easy it is for you to organise the connection to the DHN. Arranging a contract can be intimidating for people. Especially people that, for instance, cannot speak or read the Dutch language or who cannot control the language.'' (Havensteder)*

> *''You ask people to do something, and that is a barrier. People that are enthusiastic […] will do it [organise connection], while less enthusiastic people, who might do it because the neighbour does it, will not want to do it [organise connection]. People do not want the hassle.'' (050Buurtwarmte)*

Electric cooking is another potential strong barrier. Citizens often do not want to switch to electric cooking because they dislike electric cooking (Lidth de Jeude & Midden, 2014; Koning et al., 2020). Eight of the fourteen participants state citizens often dislike electric cooking because they assume it works less than a gas stove or do not understand how it works. However, three other participants argue citizens are often satisfied with electric cooking. Three participants did not mention electric cooking. Electric cooking is a potential strong barrier since eight participants mention electric cooking as a barrier and only three do not.

Controllability and heating are also potentially strong barriers. Citizens might assume DHNs insufficiently heat their dwellings and have limited control over the inside temperature (Lidth de Jeude & Midden, 2014). Eight out of fourteen participants argue citizens often assume they cannot sufficiently heat their dwellings with DHNs. Only MuPu argues citizens in Overwhere-Zuid did not assume DHNs insufficiently heat dwellings since they knew other citizens that joined the DHN. Other participants did not mention heating. Four out of fourteen participants argue citizens often assume they cannot control the temperature inside the dwelling. Other participants did not mention controllability. Similar to electric cooking, these assumptions might occur because citizens are unfamiliar with DHNs.

Outside nuisance is a limited barrier if DHNs are not combined with other work activities. Roads are partially removed to instal DHNs (Schilling et al., 2018). The work activities could burden citizens because it causes noise disturbance, and roads are temporarily inaccessible. Seven of the thirteen participants state citizens might dislike the nuisance of work activities. However, four of these seven participants argue the nuisance was mostly caused by other work activities than placing the DHN. For instance, in Overwhere-Zuid, placing the DHN was combined with sewerage replacement. The sewerage replacement mainly caused the nuisance. The three other participants argue DHNs themselves cause nuisance outside because roads are still partially removed. However, the outside nuisance of DHNs themselves might be a limited barrier because it is temporarily. Other participants did not mention outside nuisance. MuPu explains why DHN do not cause extreme nuisance:

> *''With a sewer replacement, you dig a hole of six meters deep. […] This cause a lot of noise disturbance. People complained about the noise. The nuisance had nothing to do with the DHN's placement because that is 80 centimeters deep. […] It was not a good idea to combine the DHN and sewer work activities. The sewer replacement went much slower than placing the DHN, and […] citizens went crazy due to the sound.'' (MuPu)*

Furthermore, the fear of health risks due to well-insulated dwellings potentially is no barrier because only 050Buurtwarmte argues citizens might fear the air quality inside the dwelling diminishes due to insulation. Eleven other participants argue the fear of health risks do not apply to citizens because the health risks are unknown to them, or they do not see well-insulated dwellings as a health risk. Another participant did not know if citizens fear health risks, and another participant did not mention health risks.

Comfort barriers	Barriers for homeowners and tenants	Impact of barrier
Renovation	Citizens might dislike the nuisance of dwellings' renovation, for instance, by placing underfloor heating, insulation and the heat delivery set.	Strong
Organise	Citizens might be unable or unwilling to organise the connection to a DHN.	Strong
Electric cooking	Citizens might assume that electric cooking is unpleasant.	Strong
Heating	Citizens might assume that DHNs insufficiently heat dwellings.	Strong
Controllability	Citizens might assume that they have lesser control over the indoor temperature.	Strong
Outside nuisance	Citizens might dislike the nuisance of construction work on the street. However, it is temporary.	Limited
Health	Worry about poor air quality and overheated dwellings due to well-insulated dwellings.	No barrier

Table 9: *Comfort barriers and their impact.*

4.3 Strategies to overcome citizens' barriers

This section discusses potential strategies to overcome citizens' barriers to join DHNs. Although there are some significant risks and barriers citizens face, there is a fairly high potential to find solutions, as shown in table 10.

To make homeowners willing and able to pay connection- and investment costs, the national government created finance schemes. Homeowners can get a subsidy to pay connection costs (RVO, 2021a). Additionally, homeowners can get a loan or increase their mortgage to pay investment costs (RVO, 2020b; Rijksoverheid, 2020b). Furthermore, building bound financing is another potential strategy to overcome homeowners' investment costs. Here, the loan is linked to dwellings (BZK, 2019). Although the finance schemes might help increase homeowners' willingness and ability to pay connection- and investment costs, it is not enough, according to the participants. Homeowners will still have extra costs they do not have when keeping gas. The extra costs cannot be recouped because DHN prices are equal to or slightly lower than gas prices (PBL, 2017), and sustainable investments can only partially be recouped (Schilder & Staak, 2020). Thus, the finance schemes are a limited strategy to overcome connection- and investment costs. An expert of TNO argues why subsidies are not enough:

> *''The subsidy partially will reduce the barrier. However, […] the subsidy covers a maximum of 30%. Thus, you still have to pay the other 70%.'' (TNO)*

A potentially strong strategy to overcome investment costs and renovation nuisance is reducing renovation activities. All DHN projects want to lower homeowners' investment costs by offering high-temperature DHNs (>60°C). Hereby, dwellings often do not have to be energy-efficient. Therefore, homeowners with poor-insulated dwellings are able to connect to DHNs with lower investment costs. The renovation nuisance also could be less since fewer renovation activities are needed.

However, low-temperature DHNs (<50-60°C) are more favourable than high-temperature DHNs. With low-temperature DHNs, it is easier to use renewable energy sources (Lund et al., 2014), but low-temperature DHNs are potentially only successful when buildings are energy-efficient (Ziemele et al., 2018). Therefore, 050Buurtwarmte, MuRo and MuPu wanted to advise homeowners about insulation measures. Adequately informing citizens is an aspect of citizens engagement (Gross, 2007; Barrett-Howard & Tyler, 1986; Tyler & Griffin, 1991). 050Buurtwarmte and MuRo did not yet advise homeowners. Therefore, it is unclear if the measures make more homeowners willing to renovate their dwellings. MuPu did personally advise homeowners about insulation. MuPu argues citizens engagement might make homeowners more willing to renovate their dwellings because some homeowners were interested. According to MuPu, only a few homeowners eventually insulated because the project did not pay enough attention to communicate insulation measures due to Covid-19. Thus, citizens engagement might make homeowners willing to renovate their dwellings, but it is a limited strategy since it does not make homeowners able to renovate. MuPu explains why citizens engagement is needed:

> *''If you want to talk about insulation, you need to gather all people. You need to tell a story and show them [why insulation is needed]. We have not done this enough, but we need to start with it.'' (MuPu)*

Compensation is a potential strong strategy to overcome comfort barriers, excluding organising the connection, as shown in table 10. Compensation might increase social acceptance of renewable energy projects (Río & Burguillo, 2009; Kerr et al., 2017; Rudolph et al., 2018). Eleven of the fourteen participants argue compensation might help to increase citizens' willingness to join DHNs and accept potential discomforts. Other participants did not know if compensation would help. All DHN projects compensate homeowners and tenants by offering an induction cooker and pans. The project Bospolder-Tussendijken also wants to compensate citizens by tackling citizens' personal issues, such as debts, and creating job opportunities. A participant explains why compensation potentially increases citizens' willingness:

''If people have positive associations with the project [due to compensation], they are more willing to accept less positive things.'' (050Buurtwarmte)

Compensation is also a potentially strong strategy to overcome connection- and investment costs when DHNs are high-temperature, and connection costs are (partially) paid. Compensation increases acceptability because it makes homeowners more able to join DHNs. All DHN projects offer high-temperature DHNs. Hereby, homeowners with poor-insulated dwellings can connect to the DHNs with lower investment costs. All projects largely compensate the remaining investment costs by offering induction cookers and pans. Therefore, homeowners have limited investment costs. Additionally, all DHN projects compensate homeowners' connection costs by (partially) paying the costs. The projects Paddepoel-Noord and Overwhere-Zuid wanted to compensate homeowners by fully paying their connection costs. Overwhere-Zuid and Paddepoel-Noord were able to finance the costs due to subsidy from the national program 'Aardgasvrije Wijken' (PAW). However, in Paddepoel-Noord, the costs for each dwelling were high. The municipality wanted to upscale the project to make the costs more affordable (Middel, 2020). Therefore, the Buurtwarmte project was established, and the subsidy was used for three neighbourhoods. The project is still in the initiation phase. Therefore, it is unclear how the finance scheme will be constructed. Bospolder-Tussendijken wants to finance homeowners' connection costs partially. The project offers homeowners to connect their dwellings for 1.500 euros. MuRo assumes homeowners can pay the costs because the price is similar to a new boiler. MuRo also assumes homeowners will be willing to switch because they will save many costs. Normally, the connection will cost between 9.000 and 11.000 euros. The project did not make the offer yet. Therefore, it is unclear if the offer will make homeowners able and willing to join the DHN. The project could also make the offer due to a subsidy from the PAW. Thus, the high-temperature DHN projects try to make homeowners able to connect to the DHN by compensating their connection- and investment costs. The projects were only able to compensate due to subsidies from the national government.

Furthermore, homeowners will potentially not lose investment costs if they join DHNs when their boiler needs to be replaced. Four of the fourteen participants state replacing broken boilers is only possible if the entire building block or neighborhood has to replace their boiler because DHNs require a certain number of connections to be realised. However, two other participants argue the age of boilers in neighbourhoods differ. Therefore, it is rare many boilers have a similar age in a neighbourhood. Other participants did not mention replacing broken boilers. Thus, replacing broken boilers might not be a strategy to overcome lost investment costs because the age of boilers differ. An expert explains why the age of boilers differ:

''The problem is that some boilers are ten years old, while others are new. […] Usually, buildings are very diverse. Therefore, the boilers are not of the same age.'' (CE Delft)

Three strategies have been devised by participants to overcome the lost investment costs. Four out of fourteen participants mention homeowners could sell their boiler on, for instance, Marktplaats. Thereby, homeowners get some money for their boiler. Three out of fourteen participants mention homeowners could lease a boiler if the DHN was not yet realised. Hereby, homeowners do not have purchase costs of a new boiler. Two out of fourteen participants mention homeowners could also buy a second-hand boiler if the DHN was not yet realised. Thereby, homeowners have lower purchase costs than with a new boiler. Other participants did not mention strategies. Selling boilers, leasing boilers and buying second-hand boilers could obviously help to overcome lost investment costs, but do not seem like true strategies because homeowners need to arrange the lease, sell and buy themselves and might not get enough money for their boiler. If this, for example, would be facilitated by the DHN supplier or government, they might become stronger strategies.

Network costs are potentially an important barrier because high fixed network costs potentially reinforce homeowners unwillingness to make their dwellings sustainable, and equality of gas and DHN prices might make homeowners unable to recoup connection- and investment costs. These barriers might be overcome if network costs are lowered because it potentially reduces fixed network costs and, therefore, DHN prices. A possible strong strategy to lower network costs is spreading the costs over as many citizens as possible. In the ideal case, this essentially means all energy consumers (Schilling et al., 2018). Five out of fourteen participants mention network costs should be spread over all energy users because then network costs are substantially reduced. However, two other participants argue it is unfair to let non-DHN consumers pay for DHNs. Of these two participants, RES argues heat pump consumers have higher individual costs, like purchasing heat pumps. They have lesser network costs. Therefore, heat pump consumers might be worse off. Other participants did not mention collectively paying network costs. Although it might not be fair to spread all costs over all energy consumers, it might be fair to partially spread the costs over all energy consumers. Heat pump consumers get subsidies from the government that essentially also are paid by all energy consumers (Rijksoverheid, 2021c). The costs could also be spread over only DHN consumers. Hereby, the network costs of small-scale DHNs become affordable, as mentioned in 2.2. Both strategies could be used together. The government already collectively pays a part of DHN costs in the form of subsidies, but it is questioned how much of the costs should be collectively paid. Thus, collectively paying network costs is a potential strong strategy with some important complications, also legally, that need to be arranged first. Therefore, in the short term, it does not offer a readymade answer yet.

Another possible strong strategy to lower network costs is developing DHNs on a large-scale. Eight of the fourteen participants mention when DHNs are developed large-scale, the network costs might be reduced due to economies of scale. A participant explains why economies of scale reduce network costs:

> *''The harbour in Delfzijl has many companies that have residual heat. We want to use that heat to heat dwellings in Groningen. A pipeline of 30 kilometers has to be installed for this. That will cost millions of euros. This plan is only possible if thousands of dwellings will be connected to the DHN.'' (MuGro)*

However, two of the eight participants argue economies of scale could reduce network costs to a certain extend. Other participants did not mention large-scale. A participant explains why:

> *''If you keep expanding a DHN, eventually you will need to place a new pipeline. Therefore, there are new costs.'' (OiP)*

Large-scale DHNs can also only be created when citizens are willing and able to join DHNs. DHN projects could try to collectively connect many citizens to a DHN. Hereby, the DHN projects could offer a lower price to the citizens. This strategy might be risky since DHN projects cannot legally force citizens to join DHNs. Another strategy could be that DHN projects first try to connect as many buildings as possible

that are easy to connect. Afterwards, network costs might become lower, and homeowners might be more willing and able to join DHNs. To conclude, large-scale DNHs could potentially reduce network costs to a certain extent. DHN projects should generate a large-scale by collectively connecting many citizens or first connecting buildings that are easy to connect.

Furthermore, another possible strong strategy is that DHN suppliers spread network costs over a long period. Five of the fourteen participants mention spreading network costs over a long period might make network costs more affordable, for instance, with long-term loans. Other participants did not mention spreading network costs over a long period. MuGro explains why loans make network costs affordable:

> *''We try to spread the network costs over a very long time, for example, over loans with a duration of 50 years. […] If you can spread the costs over a long time, they become affordable.'' (MuGro)*

Non-profit DHN suppliers are potentially no strategy to reduce network costs and a strong strategy to increase citizens' trust in DHNs' monopoly position and price transparency. Non-profit DHN suppliers might have lower prices than other DHN suppliers, and citizens are assured they will pay a fair price because non-profit DHN suppliers cannot make a profit. Three of the fourteen participants argue non-profit DHN suppliers are often cheaper than commercial DHN suppliers because non-profit DHN suppliers cannot make a profit. However, six other participants argue all Dutch DHN suppliers have only a minimal profit because it is limited due to the NDMA-principle, and DHN suppliers need to use the profit to make investments. Therefore, the DHN prices are similar between non-profit DHN suppliers, such as Warmtestad, and commercial DHN suppliers, such as Eneco. Additionally, nine of the thirteen participants state non-profit DHN suppliers might increase citizens' trust because the suppliers do not want to increase prices. However, Warmtestad and Stadsverwarming Purmerend are non-profit DHN suppliers and still face the monopoly position and price transparency barriers. Another participant argues citizens do not know that Stadsverwarming Purmerend is non-profit. This may explain why citizens still lack trust. Non-profit DHN suppliers should potentially inform citizens they are non-profit to increase citizens' trust. Other participants did not mention non-profit DHN suppliers. While non-profit might not significantly reduce network costs, it is a potential strong strategy to increase citizens' trust if citizens know DHN suppliers are non-profit.

A potentially strong strategy to overcome trust barriers and some comfort barriers, as shown in table 10, is citizens engagement. Citizens must perceive the planning process as fair. Thereby, citizens are more likely to perceive decisions as fair (Gross, 2007; Lind et al., 1980; Folger, 1977; Barrett-Howard & Tyler, 1986; Tyler & Rasinski, 1991), and trust in the decision-making authority increases (Gross, 2007; Tyler, 1989). Engaging citizens also potentially results in a higher social acceptance of decisions such as establishing a wind farm (Gross, 2007; Lauber, 1999). Thirteen of the fourteen participants mention citizens engagement potentially increases trust, and twelve of the fourteen participants mention citizens engagement potentially helps to overcome comfort barriers, excluding organising the connection to a DHN, because it often increases acceptance of potential discomforts. The participants mention citizens need to be engaged in the planning process by adequately informing them, create personal contact and treating them with respect. Six of the fourteen participants mention citizens also need to have a degree of control, meaning they should be free to choose between heating options. Other participants did not mention citizens engagement. All projects personally communicate with citizens to answer their questions and give them explanations. 050Buurtwarmte in Paddepoel-Noord created personal contact by organising weekly walk-in hours in the neighbourhood. In Bospolder-Tussendijken, Havensteder has someone in the neighbourhood who the residents can personally contact. Three participants explain why citizens engagement potentially overcomes comfort and trust barriers:

''Everything is about trust. Together with my team, we rented a house in the neighbourhood. […] We built personal contacts with the residents. We knew everything about their private lives, and they knew ours. […] We had a neighbourly relationship with the residents. They choose us because […] they knew we helped them.'' (MuPu)

''In the Berkenflat, lots of effort was put in explaining to citizens [how DHNs work]. One-on-one conversations with the tenants really worked.'' (MuGro)

''Informing residents [about the renovation] is important. If you clearly explain what will happen in their dwellings, they will understand that the nuisance is not so bad because it takes half a day. That makes it less scary than if you do not know what will happen in your house.'' (Grunneger Power)

Another potential strong strategy to overcome trust barriers is citizen-owned DHN projects, as shown in table 10. Local ownership is more accepted than corporate (non-local) owned renewable energy sources (Hvelplund et al., 2017; Olsen & Anker, 2014; Sovacool, 2013). Citizens might trust their neighbours more than a private company. Nine of the fourteen participants argue citizen-owned DHN projects might increase citizens' trust in DHNs because citizens have more control over the project. A participant explains why citizens ownership increases trust:

''An energy utility wants to make a profit, while a local initiative does not have that interest. Citizens also know they have control over the local initiative as a member. Everyone is the owner of an energy utility. This makes the monopoly position less scary.'' (Grunneger Power)

However, two of the nine participants and three other participants argue it is challenging to realise citizen-owned DHN projects. For instance, RES argues citizens should accept the financial risk the energy utility could go bankrupt. Two other participants did not mention citizens ownership. The Paddepoel-Noord project was a small-scale citizen-owned project that made 110 homeowners interested. However, the costs were high. The municipality wanted to upscale the project to make the costs more affordable (Middel, 2020). This also indicates it might be challenging to realise citizen-owned DHN projects. Citizens could also partially own DHNs to make citizens ownership easier. For instance, a municipality could be the shareholder of a DHN project and collaborate with a citizens initiative in a neighbourhood. Hereby, citizens have more control over the project but do not bear the financial risks. However, citizens might be unwilling to own DHN projects, according to Warmtestad. Thus, citizens ownership might increase citizens' trust, but it might be challenging to realise.

Unburdening is a possible strong strategy to overcome the organise and renovation barriers. Citizens could be unburdened by advising, informing and supporting them in sustainable renovations and financing options (BZK, 2019; Vyver et al., 2020). The construction work could also be organised in a way it reduces nuisance (SRUD, 2020). Thirteen of the fourteen participants state citizens should be unburdened by letting DHN projects organise everything. Hereby, citizens do not have to worry about the connection to the DHN. Eleven of the fourteen participants also mention citizens are unburdened by minimalising the renovation nuisance. RES did not mention unburdening. Another participant did not mention unburdening overcomes the renovation nuisance, and MuRo mentions there is already little nuisance due to reduced renovation activities. The DHN projects unburden citizens in several ways, for instance, by offering cleaning services after the renovation or placing pipes on the facade instead of indoors to reduce the inside nuisance. Two participants explain how citizens are unburdened:

''We helped clear out closets. […] Some tenants had home care. We tried to organise the renovation around these times. We also offered rest houses […] Here, they could go if the nuisance got too much.'' (Warmtestad)

''We have fully unburden citizens. They did not have to apply for a subsidy. Only a pipe was installed on the facade, and the front garden was open temporarily. […] Even the termination of the gas contract was arranged by the project.'' (SVP)

Another potential strong strategy to overcome some comfort barriers, as shown in table 10, is letting citizens experience the indoor changes. Hereby, citizens can understand the changes do not affect their comfort. Eleven of the fourteen participants state letting citizens experience the indoor changes potentially increases citizens' willingness because it disproves citizens' negative assumptions. Other participants did not mention experiencing. The DHN projects organised cooking workshops or created a model dwelling to let citizens experience indoor changes.

Furthermore, social incentives could be a limited strategy to stimulate citizens to join DHNs. Social incentives imply people experience social pressure or stimuli to change their behaviour due to the behaviour of people in their environment. Four of the fourteen participants mention that when neighbours join a DHN, citizens are potentially more willing to join as well. Other participants did not mention social incentives. DHN projects should first focus on frontrunners of the energy transition in a neighbourhood because they are more likely to join a DHN than other residents. If frontrunners are willing to connect, other residents are more likely to join as well due to social incentives. This is a limited strategy because it is uncertain if all citizens will respond to social incentives. A participant argues why social incentives might make citizens willing to join DHNs:

''People that are enthusiastic and understand why we need to have a DHN will join a DHN. While others [...] might only do it because the neighbour does it.'' (050Buurtwarmte)

Financial barriers	Impact barrier	Strategies	Impact strategy	Potential Solvability
Connection costs	Strong	- Governmental subsidies	Limited	Low
		- Compensation by fully paying costs or offering a similar price as a boiler.	Strong	High
Investment costs	Strong	- Governmental loans, increase mortgage and building bound financing.	Limited	Low
		- Reduce renovation activities by offering high temperature DHNs.	Strong	High
		- Citizens engagement meaning that citizens are adequately informed, personally contacted, treated with respect and have a degree of control over decision-making.	Limited	Low
		- Compensation with high-temperature DHNs, for instance, by offering an induction cooker and pans.	Strong	High
Lost investment costs	Limited/ Strong	- Sale of the boiler facilitated by the government or DHN supplier.	Strong	High
		- Lease of a boiler facilitated by the government or DHN supplier.	Strong	High
		- Buy of a second-hand boiler facilitated by the government or DHN supplier.	Strong	High
High fixed network costs	No barrier, but aggravates	- (Partially) paying network costs collectively by all energy consumers or by all DHN consumers	Strong	High
		- Create large-scale DHNs by collectively connecting a large number of citizens or first connecting buildings that are easy to connect.	Strong	High
		- Spreading network costs over a long period, for instance, by using long-term loans.	Strong	High
Network costs: DHN price equal to gas price	Strong	- (Partially) paying network costs collectively by all energy consumers or by all DHN consumers.	Strong	High
		- Create large-scale DHNs.	Strong	High
		- Spreading network costs over a long period	Strong	High
Unequal network costs	No barrier			
Trust barriers	**Impact barrier**	**Strategies**	**Impact strategy**	**Potential solvability**
Monopoly position	Strong	- Citizens engagement.	Strong	High
		- Non-profit DHN suppliers that are known to be non-profit.	Strong	High
		- Citizen-owned DHN projects by, for instance, making a government the shareholder of a DHN project and collaborate with a citizens initiative in a neighbourhood. However, it remains potentially challenging to realise.	Strong	High
Price transparency	Strong	- Citizens engagement.	Strong	High
		- Non-profit DHN suppliers that are known to be non-profit.	Strong	High
		- Citizen-owned DHN projects.	Strong	High
No choice between heating options	Limited	- Citizens engagement	Strong	High
		- Citizen-owned DHN projects.	Strong	High
Sustainability	Limited	- Citizens engagement.	Strong	High
		- Citizen-owned DHN projects.	Strong	High
Certainty of Supply	Limited	- Citizens engagement.	Strong	High
		- Citizen-owned DHN projects.	Strong	High
Comfort barriers	**Impact barrier**	**Strategies**	**Impact strategy**	**Potential solvability**
Renovation	Strong	- Unburdening by organising everything.	Strong	High
		- Compensation, for instance, by offering an induction cooker or creating job opportunities.	Strong	High
		- Citizens engagement	Strong	High
		- Reduce renovation activities by offering high temperature DHNs.	Strong	High
Organise	Strong	- Unburdening	Strong	High
Outside nuisance	Limited	- Compensation	Strong	High
		- Citizens engagement	Strong	High
Electric cooking	Strong	- Compensation	Strong	High
		- Citizens engagement	Strong	High
		- Experiencing indoor changes.	Strong	High
Heating	Strong	- Compensation	Strong	High
		- Citizens engagement	Strong	High
		- Experiencing indoor changes.	Strong	High
Controllability	Strong	- Compensation	Strong	High
		- Citizens engagement	Strong	High
		- Experiencing indoor changes.	Strong	High
Health	No barrier			
	Strategies		**Impact strategy**	**Potential solvability**
All barriers	- DHN projects should first focus on connecting frontrunners in a neighbourhood. In this way, other residents are more likely to join as well due to social incentives.		Limited	Low

Table 10: *Potential strategies to overcome citizens' barriers.*

5. Conclusion

This study researches barriers faced by citizens with regards to joining DHNs and how these potentially be overcome. The literature study started with an inventory of the most common risks faced when it comes to the energy transition in general. The main risks include it might affect citizens' comfort, financial situation, and perception of the environment. Social acceptance might be needed to reduce the number of citizens resisting renewable energy projects. When subsequently zooming in on DHNs, they also might affect citizens' comfort (indoors) and financial situation (risk of higher costs than potential benefits). The perception of the environment does not play a key role because, unlike solar panels and windmills, DHNs are largely located under the ground. However, trust is another potential barrier for citizens to join DHNs because citizens often lack trust in DHN suppliers (Volkova et al., 2018), decreasing social acceptance (Gross, 2007; Tyler, 1989). Therefore, based on the preliminary literature review, citizens' barriers to join DHNs are divided into financial, trust and comfort barriers. Homeowners only have financial barriers because they have to pay the costs, while housing corporations pay the costs for tenants (RVO, 2020c). Obviously, also housing corporations will face financial barriers, but that has not been the focus of this study. Trust and comfort are barriers for both tenants and homeowners.

The empirical study aimed to further substantiate or nuance the risks identified in the literature whilst also engaging with how barriers might be overcome or have been overcome in practice. Theretofore, four Dutch cases are studied based on nine interviews and five additional expert interviews. The findings of this study largely confirm the barriers identified in the literature but add further content, context and nuance. To begin with, financial barriers were indeed shown to be most crucial. In line with the literature review, the financial barriers connection- and investment costs might have the strongest influence on homeowners willingness and ability to join DHNs because these are extra costs homeowners do not have when keeping gas. Making dwellings sustainable is often financially unattractive for homeowners because the savings on the energy bill do not outweigh the costs (Schilder & Staak, 2020). The results show, similar to the literature, under the current circumstances, the costs cannot be recouped by a lower energy bill because DHN prices are equal to or slightly lower than gas prices (PBL, 2017). Furthermore, in line with the literature, DHNs' fixed network costs are high, and variable consumption costs are low (Hers et al., 2018). Therefore, homeowners cannot reduce their energy bills when making their dwellings sustainable. Although the literature indicates network costs differ between DHN projects (Schilling et al., 2018), the findings show inequality in network costs is no barrier because network costs only slightly differ. Additionally, in line with the literature review, investments, like purchasing boilers, are potentially lost when switching to DHNs. Lost investment costs might make homeowner's unwilling to join DHNs.

In the face of the serious financial barriers, also few successful solution strategies are visible. The most used and appreciated are governmental subsidies to pay connection costs, but also governmental loans and increasing the mortgage to pay investment costs. Building bound financing, in which the loan is linked to dwellings, might also help pay investment costs. In line with the literature review, these finance schemes could potentially solve just part of the connection- and investment costs because homeowners still have extra costs they do not have when keeping gas and cannot recoup them (Schilder & Staak, 2020). The findings of this study suggest reducing renovation activities by offering high-temperature DHNs might significantly lower investment costs. Furthermore, enriching the literature, the findings suggest high-temperature DHNs that compensate homeowners investment costs by offering induction cookers and pans might make homeowners more able to pay investment costs. Compensation by fully paying connection costs or offering a similar price as a boiler might also make homeowners more able to pay connection costs. However, additional subsidy from the national government seems crucial to make DHN projects able to compensate. Network costs need to be reduced because then DHN prices might become lower than gas prices, and DHNs' high fixed network costs might become lower. Hereby, less compensation is needed because homeowners might be able

to recoup their costs. Alternative strategies that might bring down overall costs exist. Adding to the literature on collectively paying network costs, all energy consumers could partially pay DHNs' network costs. Hereby, the network costs will potentially become lower for DHN consumers because they are spread over many citizens. In line with the literature, network costs could also be spread over only DHN consumers (Schilling et al., 2018). Therefore, the network costs of small-scale DHNs potentially become more affordable. Both strategies could be used together. Collectively paying network costs does not offer a ready-made answer yet because it could be questioned how much of the network costs should be collectively paid and how it needs to be arranged legally. In line with the literature review, network costs might also be reduced by spreading network costs over a long period by using long-term loans and creating large-scale DHNs due to economies of scale. Adding to the literature review, large-scale DHNs could be created by collectively connecting many citizens or first connecting buildings that are easy to connect. Unlike the literature review suggested, the findings also show making DHN suppliers non-profit does not seem to reduce network costs since DHN prices are similar between non-profit and commercial DHN suppliers. Although the literature review indicates replacing the broken boiler is a potential strategy to overcome lost investment costs, the findings suggest it is no strategy. The age of boilers differs, while DHNs require a certain number of connections to be realised. The results suggest DHN suppliers or governments should sell boilers, lease boilers or buy second-hand boilers for homeowners. Hereby, lost investment costs are potentially reduced.

Trust is the second key barrier identified in this study and is largely in line with the literature. First, citizens fear they will pay an unfair price. This has several causes. To begin with, it is especially connected to DHN suppliers' monopoly position. In line with the literature, citizens often fear they will pay an unfair price (Which?, 2015) and thus fear they are stuck to one DHN supplier who raises the price (Upham & Jones, 2012). Next, price transparency also strengthens the fear of paying an unfair price. In line with the literature, it is often unclear how DHN prices are constructed (Which?, 2015) and difficult to compare with other heating alternatives (Bouw, 2016). Citizens might thus feel worse off with DHNs, even if this is not the case (Lidth de Jeude & Midden, 2014; Koning et al., 2020). The findings also indicate citizens might dislike they cannot choose between other heating alternatives. This is in line with the literature. When citizens do not have a degree of control over decision-making, citizens could perceive the project as unfair, leading to lower acceptance (Tyler & Griffin, 1991; Kitzmann & Emery, 1993). However, in line with the literature, the findings suggest citizens possibly have lower acceptance because they are inadequately informed (Gross, 2007; Barrett-Howard & Tyler, 1986; Tyler & Griffin, 1991). Therefore, having no choice between heating alternatives might only be a limited barrier. Secondly, trust relates to the physical characteristics of DNHs. On the one hand, sustainability of the energy source. Although the literature indicates if DHNs are not (fully) sustainable, citizens might be unwilling to join DHNs (Upham & Jones, 2012), the findings show citizens often do not care about sustainability. Therefore, sustainability might have a limited influence on citizens' willingness. On the other hand, DHNs' technical reliability. Although the literature indicates citizens might be concerned about DHNs' technical reliability (Upham & Jones, 2012; Lidth de Jeude & Midden, 2014), the results show citizens often trust the technical reliability of DHNs. Therefore, certainty of supply might have a limited influence on citizens' willingness.

In the face of the risks when it comes to trust, various potential strategies can be used to reduce or prevent the perceived risks. First, making DHN suppliers non-profit. The strategy increases citizens' trust in DHNs' monopoly position and price transparency. In line with the literature review, citizens are assured they will pay a fair price because non-profit suppliers cannot make a profit. Adding to the literature review, it should be known to the public that DHN suppliers are non-profit. Secondly, citizen-owned DHN projects might increase citizens' trust and overcome trust barriers. In line with the literature, local ownership is more accepted than corporate (non-local) owned renewable energy sources (Hvelplund et al., 2017; Olsen & Anker, 2014; Sovacool, 2013). It might be challenging to realise citizen-owned DHN projects because it is too financially risky for them. To potentially make it less financially risky, municipalities could be shareholders of DHN projects and collaborate with citizens

initiatives in neighbourhoods. However, the findings show it remains challenging to realise citizen-owned DHN projects because citizens might be unwilling to own DHN projects. Therefore, it is a solution with some complications. Among the key strategies that might help solve trust barriers are increasing and improving forms of citizens engagement. This strategy will be explained below after comfort barriers are discussed, as this is also a strategy for comfort barriers.

Comfort is the third key barrier. The findings of this study largely confirm the comfort barriers identified in the literature. The comfort barrier renovation is a potential strong barrier because the nuisance of the renovation cannot be prevented. In line with the literature, citizens often do not want their dwellings to be turned upside down for the renovation (Hajer, 2020). Organising the connection to the DHN is another potential strong barrier because citizens might be unable or unwilling to do this. In line with the literature, the loads of work could burden citizens (BZK, 2019; Juwet, 2020). The findings also show the nuisance of work activities outside could make citizens less willing to join DHNs. However, the barrier is limited because the nuisance is temporary. Furthermore, in line with the literature, citizens often dislike electric cooking (Lidth de Jeude & Midden, 2014; Koning et al., 2020) because they often assume it works less than gas stoves (Koning et al., 2020). Citizens also, similar to the literature, potentially assume DHNs insufficiently heat dwellings, and they have limited control over the temperature (Lidth de Jeude & Midden, 2014). The barriers of electric cooking, heating and controllability might be strong because they potentially make citizens less willing to join DHNs. The literature also indicates well-insulated dwellings could lead to poor air quality and overheated dwellings (Nazaroff, 2013; Haines et al., 2007). However, the findings show health risks or fear of health risks are no barrier because they are unknown to citizens or well-insulated dwellings are not seen as a health risk.

In the face of the comfort barriers, also successful solution strategies are visible. The results show renovation nuisance could potentially be reduced when renovation activities are reduced. In line with the literature, unburdening is another potential strategy to overcome the organise and renovation barriers because citizens do not have to organise the connection (BZK, 2019; Vyver et al., 2020), and the renovation is organised in a way that the nuisance is minimised (SRUD, 2020). Furthermore, in line with the literature review, the barriers electric cooking, heating and controllability might be highly solvable because the assumptions of these barriers might be easily disproved by letting citizens experience the indoor changes. Additionally, compensation is a potential strategy to overcome comfort barriers, excluding organising the connection to a DHN, because, in line with the literature, compensation might increase social acceptance of renewable energy projects (Río & Burguillo, 2009; Kerr et al., 2017; Rudolph et al., 2018) and thus potential indoor changes. The results further show citizens might be compensated by, for instance, offering induction cookers.

A potentially important strategy to overcome trust and comfort barriers, excluding organising the connection to a DHN, is citizens engagement. The empirical results of this study are largely in line with the literature that citizens must perceive the planning process as fair. Thereby, citizens are more likely to perceive decisions as fair (Gross, 2007; Lind et al., 1980; Folger, 1977; Barrett-Howard & Tyler, 1986; Tyler & Rasinski, 1991), and so trust in decision-making authorities increase (Gross, 2007; Tyler, 1989). Additionally, engaging citizens results in higher social acceptance of renewable energy projects (Gross, 2007; Lauber, 1999). This study presented similar findings. Citizens engagement increases acceptance of potential discomforts citizens get when joining DHNs. The results further show citizen engagement means citizens are adequately informed, personally contacted, treated with respect and have a degree of control over decision-making. Adding to the literature, citizens engagement also might partly counteract investment costs. Citizens engagement might make homeowners more willing to renovate their dwellings. However, it does not reduce financial costs and thus remains limited as a strategy. Furthermore, social incentives could potentially stimulate citizens to join DHNs. The findings show social incentives imply people experience social pressure or stimuli to change their behaviour due to the behaviour of people in their environment. The findings further show DHN projects might first focus

on connecting frontrunners in a neighbourhood. Hereby, other residents are more likely to join as well due to social incentives. However, the strategy has limitations because not all citizens will similarly respond to social incentives or at all.

All in all, DHN projects should potentially engage citizens in the planning process by adequately informing them, personally contacting them, treating them with respect and giving them a degree of control over decision-making. Citizens engagement potentially increases social acceptance of DHN projects and trust in DHNs. Many misconceptions can then be avoided, which makes it easier to realise DHNs. Furthermore, DHN projects should potentially compensate citizens by, at least, offering induction cookers, but unburdening by offering extensive administrative support is also a key strategy to increase citizens' uptake and support of DHNs. Compensation is also needed to finance connection costs or, if needed, investment costs. Hereby, homeowners are more able to join DHNs. However, DHN projects can only compensate with subsidies from the national government, whilst having a large-scale will at least contribute to lower finances. This indicates the national government should (partially) finance DHN projects, support the upscaling of projects and potentially socialise a degree of the DHNs' costs. When the national government finances and supports DHN projects, DHN prices might be reduced, making homeowners able to recoup their costs by a lower energy bill in a reasonable time. When more citizens can join DHNs, DHN prices could also be reduced due to economies of scale. Therefore, in the long term, less compensation of DHN projects is needed. Additionally, the national government might spread network costs over all DHN consumers. Thereby, small-scale DHN projects become more affordable, and it becomes less financially risky to realise citizen-owned DHN projects. Citizens ownership will potentially make more citizens willing to join DHNs. Another way the national government should make more citizens willing to join DHNs is to make all DHN suppliers non-profit. This might help to increase trust in DHN suppliers. Thus, in the short term, the national government should support DHN projects to increase the number of citizens joining DHNs. In the long term, this might make more citizens willing and able to join DHNs, and the aims of the Paris agreement could be reached.

6. Discussion

When looking back at the analytical framework and literature review conducted, there are some relevant changes. The outside nuisance is not identified as a barrier in the literature review. In retrospect, this should be added to the academic framework as the barrier is deducted from the interviews as being relevant. No choice between heating alternatives is another barrier deducted from the interviews but should also be added to the academic framework. Tyler and Griffin (1991) and Kitzmann and Emery (1993) argue citizens could perceive projects as unfair when they do not have a degree of control over decision-making, leading to lower acceptance. Reducing renovation activities to overcome investment costs and renovation nuisance is a strategy deducted from the interviews and should also be added to the academic framework. According to Kruit and Schepers (2019), high-temperature DHNs make poor-insulated dwellings able to connect to DHNs. Therefore, poor-insulated dwellings do potentially not need to be insulated, reducing investment costs and renovation nuisance. Although the barriers and strategy were not identified in the academic framework, semi-structured interviews have helped prevent them from being overlooked.

Additionally, the strategy to use social incentives was deducted from the interviews. However, social incentives are also discussed in scientific literature. Social norms could create social incentives for citizens to join DHNs. Social norms are unwritten rules, prescribing how citizens should act given their social surroundings and circumstances (Hechter & Opp, 2001). According to Huijts et al. (2012), social norms are expressed in the social pressure citizens experience to display certain behaviour. In social norms, the expected reaction of others plays a central role, as does the influence of citizens' opinions on their opinion. An example of a social incentive could be that if neighbours do something, it will be assumed fine and thus more acceptable. Further research is needed to study the impact of social incentives on citizens' willingness to join DHNs.

Furthermore, according to the participants, citizens are often not concerned about sustainability. However, according to a CBS report, 53% of Dutch citizens are (highly) positive about switching from gas to sustainable energy (Kloosterman et al., 2021). Hence, more than half of Dutch citizens are concerned about sustainability. This might indicate that the participants have insufficient knowledge of approaching citizens to make them enthusiastic about DHNs. It might be the case DHN projects often focus too much on the rational aspects, such as financial, and less on the emotional aspects, such as greener neighbourhoods. If DHN projects focus more on the emotional aspects, such as making a neighbourhood greener, they potentially increase social acceptance of DHNs.

This study did not question citizens themselves because it was impossible to organise focus groups or approach residents by entering the neighbourhood due to the Covid-19 pandemic. It is important to keep in mind citizens' barriers to join DHNs might differ due to age, social norms and income. For instance, the elderly might not want to make their dwellings sustainable because they wonder if they can financially benefit from the renovation. Whilst young starters might want to make their dwellings sustainable but do not have money because they bought their first dwelling (BZK, 2019). Further research is needed to identify if barriers differ due to age, social norms and income.

This study also focuses on tenants of housing corporations. The barriers between tenants of housing corporations and private housing might differ. Tenants of housing corporations might have low incomes because housing corporations often only offer rental homes for low-income households (Rijksoverheid, 2021a). Tenants of housing corporations might be more sceptical about DHN prices than of private housing because tenants of housing corporations might be less able to afford high prices. The study also did not focus on housing corporations and landlords, while these also face financial barriers. Further research is needed to identify differences in barriers between tenants of housing corporations and private housing, but also barriers of housing corporations and landlords.

Additionally, barriers marked as 'little or no' and 'limited' in the checklist were not questioned due to limited time. Therefore, it is unclear if a barrier marked as a barrier in a DHN project could be no barrier in another DHN project. For instance, organising the connection to a DHN could be no barrier for a DHN project because homeowners are fully unburdened, while organise could be a strong barrier in another project because homeowners are not unburdened. Likewise, if strategies were not used by DHN projects or strategies that potentially overcome barriers marked with 'little or no' and 'limited' in the checklist were not questioned due to limited time. Therefore, it is unclear if the strategies might be less useful for certain projects. For instance, if a DHN project did not see network costs as a barrier, it might still be that generating large-scale DHNs are useful. Follow-up research is needed to study which factors cause some barriers are no barriers anymore and which strategies are important no matter what the barriers are.

Moreover, this study can be generalised to a limited extent because different barriers could occur for each best practice. DHNs are dependent on the resources in their area. Therefore, the location of best practices influences barriers that emerge. For instance, Bospolder-Tussendijken in Rotterdam has economies of scale in comparison to Paddepoel-Noord in Groningen, which has fewer residents. Therefore, network costs might be lower in Bospolder-Tussendijken, making network costs less of an issue than in Paddepoel-Noord. Nevertheless, saturation is reached because the more interviews were conducted, the more this did not lead to new information (Longhurst, 2010).

The first research strategy was to research three best practices. When the researcher conducted the interview with Havensteder, it became evident the project did not yet have tenants' permission. Therefore, the participant could only discuss tenants' barriers. To discuss strategies to overcome tenants' barriers, the researcher decided to add another best practice, namely the Berkenflat. This project got permission from the tenants to connect the flat.

At last, it became evident not all participants were comfortable answering all questions. The researcher tried to make participants able to openly answer questions by making participants anonymous.

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Appendix 1 Checklists

Barrières voor burgers om aan te sluiten op uw warmtenet	**Niet of nauwelijks een barrière (- -)**	**Beperkt een barrière (-)**	**Neutraal (0)**	**Sterk een barrière (+)**	**Heel sterk een barrière (++)**	**Niet van toepassing (n.v.t.)**
Financiële barrières						
1. In hoeverre zijn aansluitkosten een barrière voor burgers om over te stappen op uw warmtenet? (Aansluiting woning aan warmtenet en/of huur warmte-afleverset)						
2. In hoeverre zijn nieuwe investeringen in woningen een barrière voor burgers om over te stappen op uw warmtenet? (Plaatsen van Isolatie, vloerverwarming en gas fornuis vervangen)						
3. In hoeverre zijn verloren investeringskosten een barrière voor burgers om over te stappen op uw warmtenet? (Investering in Cv-ketel verloren)						
4. In hoeverre is de ongelijkheid in netwerkkosten tussen warmtenet projecten een barrière voor burgers om over te stappen op uw warmtenet? (Netwerkkosten zijn de kosten voor het aanleggen en onderhouden van de infrastructuur, zonder de aansluiting van de woning)						
5. De vaste kosten in de warmtenet prijs zijn hoger dan bij de gas prijs. Hierdoor kunnen burgers nauwelijks hun energierekening verlagen door hun consumptiegedrag aan te passen. In hoeverre is het nauwelijks kunnen verlagen van de energierekening een barrière voor burgers om over te stappen op uw warmtenet?						
6. De energierekening die consumenten betalen voor een warmtenet is bijna gelijk aan gas. In hoeverre is dit een barrière voor burgers om over te stappen op uw warmtenet?						
Comfort barrières						
7. Denken burgers dat hun huizen niet voldoende verwarmd kunnen worden met een warmtenet? In hoeverre is dit een barrière voor burgers om over te stappen op uw warmtenet?						
8. In hoeverre is het hebben van minder controle over de temperatuur een barrière voor burgers om over te stappen op uw warmtenet?						
9. In hoeverre is het overstappen op elektrisch koken een barrière voor burgers om over te stappen op uw warmtenet?						
10. Vrezen burgers dat als hun huis goed geïsoleerd wordt zij een slechtere luchtkwaliteit en oververhitte woningen zullen hebben? In hoeverre is dit een barrière voor burgers om over te stappen op uw warmtenet?						
11. In hoeverre is het een barrière voor burgers om de aansluiting van hun woning aan uw warmtenet te regelen?						
12. In hoeverre is het een barrière voor burgers dat de renovatie binnenshuis voor overlast zou gaan zorgen? (isoleren, vloerverwarming, gas fornuis eruit)						
Vertrouwens barrières						
13. In hoeverre is het gebrek aan transparantie over de warmtenet prijs een barrière voor burgers om aan te sluiten op uw warmtenet?						

14. Kunnen burgers de warmtenet prijs moeilijk vergelijken met andere warmte alternatieven? In hoeverre is dit een barrière voor burgers om aan te sluiten op uw warmtenet?						
15. In hoeverre is het wantrouwen van burgers op de monopoly positie van de warmtenet leverancier een barrière om aan te sluiten op uw warmtenet?						
16. In hoeverre is het geen keuzevrijheid hebben van leverancier een barrière voor burgers om aan te sluiten op uw warmtenet?						
17. In hoeverre is de argwaan van burgers over de duurzaamheid van warmtenetten een barrière voor hun om aan te sluiten op uw warmtenet?						
18. Hebben burgers geen vertrouwen in de technische betrouwbaarheid van uw warmtenet? In hoeverre is dit een barrière voor hun om aan te sluiten op uw warmtenet?						
Ziet u naast bovenstaande barrières nog een andere barrière?:						
Ziet u naast bovenstaande barrières nog een andere barrière?:						

Barrières voor burgers om aan te sluiten op warmtenetten	**Niet of nauwelijks een barrière (- -)**	**Beperkt een barrière (-)**	**Neutraal (0)**	**Sterk een barrière (+)**	**Heel sterk een barrière (++)**	**Niet van toepassing (n.v.t.)**
Financiële barrières						
1. In hoeverre zijn aansluitkosten een barrière voor burgers om over te stappen op warmtenetten? (Aansluiting woning aan warmtenet en/of huur warmte-afleverset)						
2. In hoeverre zijn nieuwe investeringen in woningen een barrière voor burgers om over te stappen op warmtenetten? (Plaatsen van Isolatie, vloerverwarming en gas fornuis vervangen)						
3. In hoeverre zijn verloren investeringskosten een barrière voor burgers om over te stappen op warmtenetten? (Investering in Cv-ketel verloren)						
4. In hoeverre is de ongelijkheid in netwerkkosten tussen warmtenet projecten een barrière voor burgers om over te stappen op warmtenetten? (Netwerkkosten zijn de kosten voor het aanleggen en onderhouden van de infrastructuur, zonder de aansluiting van de woning)						
5. De vaste kosten in de warmtenet prijs zijn hoger dan bij de gas prijs. Hierdoor kunnen burgers nauwelijks hun energierekening verlagen door hun consumptiegedrag aan te passen. In hoeverre is het nauwelijks kunnen verlagen van de energierekening een barrière voor burgers om over te stappen op warmtenetten?						
6 De energierekening die consumenten betalen voor een warmtenet is bijna gelijk aan gas. In hoeverre is dit een barrière voor burgers om over te stappen op warmtenetten?						
Comfort barrières						
7. Denken burgers dat hun huizen niet voldoende verwarmd kunnen worden met een warmtenet? In hoeverre is dit een barrière voor burgers om over te stappen op warmtenetten?						
8. In hoeverre is het hebben van minder controle over de temperatuur een barrière voor burgers om over te stappen op warmtenetten?						
9. In hoeverre is het overstappen op elektrisch koken een barrière voor burgers om over te stappen op warmtenetten?						
10. Vrezen burgers dat als hun huis goed geïsoleerd wordt zij een slechtere luchtkwaliteit en oververhitte woningen zullen hebben? In hoeverre is dit een barrière voor burgers om over te stappen op warmtenetten?						
11. In hoeverre is het een barrière voor burgers om de aansluiting van hun woning aan warmtenetten te regelen?						
12. In hoeverre is het een barrière voor burgers dat de renovatie binnenshuis voor overlast zou gaan zorgen? (isoleren, vloerverwarming, gas fornuis eruit)						
Vertrouwens barrières						
13. In hoeverre is het gebrek aan transparantie over de warmtenet prijs een barrière voor burgers om aan te sluiten op warmtenetten?						
14. Kunnen burgers de warmtenet prijs moeilijk vergelijken met andere warmte alternatieven? In hoeverre is dit een barrière voor burgers om aan te sluiten op warmtenetten?						

15. In hoeverre is het wantrouwen van burgers op de monopoly positie van warmtenet leveranciers een barrière om aan te sluiten op warmtenetten?						
16. In hoeverre is het geen keuzevrijheid hebben van leverancier een barrière voor burgers om aan te sluiten op warmtenetten?						
17. In hoeverre is de argwaan van burgers over de duurzaamheid van warmtenetten een barrière voor hun om aan te sluiten op warmtenetten?						
18. Hebben burgers geen vertrouwen in de technische betrouwbaarheid van warmtenetten? In hoeverre is dit een barrière voor hun om aan te sluiten op warmtenetten?						
Ziet u naast bovenstaande barrières nog een andere barrière?:						
Ziet u naast bovenstaande barrières nog een andere barrière?:						

Appendix 2 Interview Guides

Interview vragen experts

Inleiding

- Korte uitleg onderzoek (uitleg barrières geven).
- Leg uit waarom je de deelnemer wilt interviewen.
- De deelnemer zal anoniem blijven. Zijn functie zal wel worden genoemd mits de deelnemer toestemming geeft.
- De organisatie of het warmtenet project zal wel worden genoemd, omdat dit helpt bij een beeld krijgen van de kennis van de deelnemer en de karakteristieken van het warmtenet project.
- Leg uit wat er met de data zal gebeuren.
- Vraag of het interview opgenomen mag worden.
- Leg uit dat het interview altijd stopgezet mag worden door de deelnemer.
- Ik verwacht dat ik eind juni de thesis afgerond zal hebben. Ik zal u ter inzage de conceptversie sturen. Als u opmerkingen heeft dan kunt u deze voor 21 juni aangeven.
- Vraag of de deelnemer nog vragen heeft.
- Laat de deelnemer het toestemmingsformulier ondertekenen.

Introductie vragen

1. Kunt u kort iets vertellen over uw organisatie?
2. Wat houden uw werkzaamheden precies in?
3. - Wat is uw eigen disciplinaire achtergrond?

Energietransitie algemeen

1. In hoeverre denkt u dat de warmtetransitie anders is dan de energietransitie in het algemeen en leidt de warmtetransitie volgens u tot andere barrières en uitdagingen?

Financiële barrières

1. Op het lijstje van financiële barrières heeft u bij een aantal **sterk en heel sterk** ingevuld. Kunt u aangeven waarom dit barrières zijn en hoe deze barrières worden overkomen door warmtenet projecten?

Financiële barrières overkomen

Barrière 1 en 2

Aansluit- en investeringskosten overkomen

1. In hoeverre hebben overheidssubsidies geholpen bij het overkomen van problemen met aansluit- en investeringskosten? (Later vragen ISDE)
2. In hoeverre hebben overheidsleningen geholpen bij het overkomen van problemen met aansluit- en investeringskosten? (Later vragen warmtefonds)
3. In hoeverre denkt u dat de mogelijkheid voor burgers om hun hypotheek te verhogen om investeringen te betalen helpt bij het overkomen van problemen met aansluit- en investeringskosten?
4. In hoeverre denkt u dat op de lange termijn aflossen van aansluit - en investeringskosten geholpen heeft bij het overkomen van aansluit- en investeringskosten?
5. In hoeverre denkt u dat gebouwgebonden financiering zou werken om problemen met aansluit- en investeringskosten te overkomen?
    a. Zo ja, hoe denkt u dat dit mogelijk is?

Barrière 3

Verloren investeringskosten overkomen

6. Worden burgers benaderd op het moment dat hun cv-ketel vervangen moet worden?
    a. Zorgt dit ervoor dat burgers willen overstappen?

Barrière 4, 5 en 6
Netwerk kosten overkomen

7. In hoeverre ziet u het opschalen van warmtenetten als een effectieve strategie om netwerkkosten te verlagen?
    a. Zorgt dit ervoor dat burgers willen overstappen?
8. Denkt u dat het socialiseren van netwerk kosten een oplossing kan zijn om netwerk kosten voor elk warmtenet project betaalbaar te maken?
    a. Waarom wel of niet?
    b. Zo ja, over wie moeten deze kosten worden verspreid?
9. Mogen warmtebedrijven winst maken? Zo niet:
    a. Zorgt dit ervoor dat prijzen lager zijn en daardoor burgers eerder willen overstappen?
10. Worden investeringskosten bij het bouwen van de infrastructuur door warmtenetten verspreid over een lange termijn?
    a. Wordt hierdoor voorkomen dat netwerk kosten hoog zijn?

Algemene vraag financiële barrières overkomen

11. Doet de nationale overheid volgens u genoeg om financiële barrières op te lossen?
    - Waarom vindt u van wel of niet en kunt u voorbeelden geven?

Comfort en Vertrouwens barrières

1. Op het lijstje van comfort en vertrouwens barrières heeft u bij een aantal **sterk en heel sterk** ingevuld.
   Kunt u aangeven waarom dit barrières zijn en hoe deze barrières worden overkomen door warmtenet projecten?

Comfort en Vertrouwens barriers overkomen

Barrière 7, 8, 9 en 10
Heating, Controllability, Electric cooking, Health overkomen

1. In hoeverre laten warmtenet projecten burgers ervaren hoe het zal zijn als ze zouden overstappen op warmtenetten?
    a. Helpt dit om bepaalde barrières op te heffen? Zo ja welke barrières?

Barrière 7, 8, 9, 10 en 12
Heating, controllability, electric cooking, health en renovatie overkomen

2. In hoeverre worden burgers gecompenseerd als ze overstappen op warmtenetten? Bijvoorbeeld financieel, door het creëren van werk, door burger eigenaar te maken enzovoort.
    a. Helpt dit om bepaalde comfort barrières op te heffen?

Barrière 11 en 12
Renovatie en organize overkomen

3. In hoeverre worden burgers ontzorgd in warmtenet projecten bij het organiseren van de connectie van de woning op het warmtenet?
   a. Hoe worden burgers ontzorgd?
   b. Helpt dit om bepaalde barrières op te heffen? Zo ja welke barrières?

Barrière 7, 8, 9, 10, 12, 13, 14, 15, 16, 17 en 18
Heating, Controllability, Electric cooking, Health, Renovation, Price transparancy, Price comparability, Monopoly, Freedom of choice, Sustainability en Certainty of supply overkomen

4. In hoeverre betrekken warmtenet projecten burgers in het planningsproces?
    a. Op welke manier worden burgers betrokken?
    b. Helpt dit om bepaalde comfort en vertrouwens barrières op te heffen? Zo ja welke barrières?

Barrière 14, 14, 13, 16, 17 en 18
Price transparancy, Price comparability, Monopoly, Freedom of choice, Sustainability en Certainty of supply overkomen

5. In hoeverre zijn burgers eigenaar van warmtenetten?
    a. In hoeverre helpt dit bij het overkomen van bepaalde vertrouwens barrières? Zo ja welke barrières?

Barrière 13 en 15
Price transparancy en Monopoly overkomen

1. (Wss al gevraagd) Moge warmtebedrijven winst maken? Zo niet:
    a. In hoeverre heeft dit geholpen bij het overkomen van bepaalde vertrouwens barrières? Zo ja welke barrières?

Algemene vragen

1. Als u kijkt naar uw eigen organisatie. Denkt u dat uw organisatie voldoende in huis heeft qua financiën, kennis en kunde om warmtenetten te helpen realiseren?
2. Als u kijkt naar organisaties waarmee u veel moet samenwerken. Bijvoorbeeld gemeentes, burgerinitiatieven, woning corporaties en warmtebedrijven. Denkt u dat zij voldoende in huis hebben qua financiën, kennis en kunde om warmtenetten te realiseren?
3. Ziet u nog contextuele factoren die de voortgang van warmtenetten in de weg zitten? (nationale wetgeving, de media, politiek enzovoort)
4. Als u drie dingen mag noemen die moeten veranderen om de warmtetransitie makkelijker te maken, wat zou er dan moeten veranderen?

Neutrale barrières (indien tijd over)

1. Op het lijstje van barrières heeft u bij een aantal **neutraal** ingevuld. Kunt u aangeven waarom u neutraal heeft ingevuld?
    - Waarom is het wel/niet een barrière?
    - Hoe worden deze barrières overkomen?

Afsluiting:
Dit is het einde van het interview. Ik wil u nogmaals bedanken voor uw medewerking. Heeft u nog vragen?

Interview vragen casussen warmtenet projecten

Inleiding

- Korte uitleg onderzoek (uitleg barrières geven).
- Leg uit waarom je de deelnemer wilt interviewen.
- De deelnemer zal anoniem blijven. Zijn functie zal wel worden genoemd mits de deelnemer toestemming geeft.
- De organisatie of het warmtenet project zal wel worden genoemd, omdat dit helpt bij een beeld krijgen van de kennis van de deelnemer en de karakteristieken van het warmtenet project.
- Leg uit wat er met de data zal gebeuren.
- Vraag of het interview opgenomen mag worden.
- Leg uit dat het interview altijd stopgezet mag worden door de deelnemer.
- Ik verwacht dat ik eind juni de thesis afgerond zal hebben. Ik zal u ter inzage de conceptversie sturen. Als u opmerkingen heeft dan kunt u deze voor 21 juni aangeven.
- Vraag of de deelnemer nog vragen heeft.
- Laat de deelnemer het toestemmingsformulier ondertekenen.

Introductie vragen

4. Kunt u kort iets vertellen over uw organisatie?
   - Hoeveel aansluitingen heeft uw warmtenet project en wat voor type woningen zijn het?
5. Wat houden uw werkzaamheden precies in?
   - Wat is uw eigen disciplinaire achtergrond?

Energietransitie algemeen

2. In hoeverre denkt u dat de warmtetransitie anders is dan de energietransitie in het algemeen en leidt de warmtetransitie volgens u tot andere barrières en uitdagingen?

Financiële barrières

2. Op het lijstje van financiële barrières heeft u bij een aantal **sterk en heel sterk** ingevuld. Kunt u aangeven waarom dit barrières zijn en hoe deze barrières worden overkomen door uw warmtenet project?

Financiële barrières overkomen

Barrière 1 en 2

Aansluit- en investeringskosten overkomen

12. In hoeverre hebben overheidssubsidies geholpen bij het overkomen van problemen met aansluit- en investeringskosten? (Later vragen ISDE)
13. In hoeverre hebben overheidsleningen geholpen bij het overkomen van problemen met aansluit- en investeringskosten? (Later vragen warmtefonds)
14. In hoeverre denkt u dat de mogelijkheid voor burgers om hun hypotheek te verhogen om investeringen te betalen helpt bij het overkomen van problemen met aansluit- en investeringskosten?
15. In hoeverre denkt u dat op de lange termijn aflossen van aansluit - en investeringskosten geholpen heeft bij het overkomen van aansluit- en investeringskosten?
16. In hoeverre denkt u dat gebouwgebonden financiering zou werken om problemen met aansluit- en investeringskosten te overkomen?
    a. Zo ja, hoe denkt u dat dit mogelijk is?

Barrière 3

Verloren investeringskosten overkomen

17. Hebben jullie burgers benaderd op het moment dat hun cv-ketel vervangen moest worden?
    a. Heeft dit ervoor gezorgd dat burgers wilden overstappen?

Barrière 4, 5 en 6
Netwerk kosten overkomen

18. In hoeverre ziet u het opschalen van warmtenetten als een effectieve strategie om netwerkkosten te verlagen?
    a. Zorgt dit ervoor dat burgers willen overstappen?
19. Denkt u dat het socialiseren van netwerk kosten een oplossing kan zijn om netwerk kosten voor elk warmtenet project betaalbaar te maken?
    a. Waarom wel of niet?
    b. Zo ja, over wie moeten deze kosten worden verspreid?
20. Mag jullie bedrijf winst maken? Zo niet:
    a. Zorgt dit ervoor dat jullie prijzen lager zijn en daardoor burgers eerder willen overstappen?
21. Heeft u het investeringskosten bij het bouwen van de infrastructuur kunnen spreiden over een lange termijn?
    a. Heeft u hierbij kunnen voorkomen dat uw hoge netwerk kosten had?

Algemene vraag financiële barrières overkomen

1. Doet de nationale overheid volgens u genoeg om financiële barrières op te lossen?
   - Waarom vindt u van wel of niet en kunt u voorbeelden geven?

Comfort en Vertrouwens barrières

2. Op het lijstje van comfort en vertrouwens barrières heeft u bij een aantal **sterk en heel sterk** ingevuld.
   Kunt u aangeven waarom dit barrières zijn en hoe deze barrières worden overkomen door uw warmtenet project?

Comfort en Vertrouwens barriers overkomen

Barrière 7, 8, 9 en 10
Heating, Controllability, Electric cooking, Health overkomen

6. In hoeverre heeft uw warmtenet project burgers laten ervaren hoe het zal zijn als ze zouden overstappen op uw warmtenet?
   b. Helpt dit om bepaalde comfort en vertrouwens barrières op te heffen? Zo ja welke barrières?

Barrière 7, 8, 9, 10 en 12
Heating, controllability, electric cooking, health en renovatie overkomen

7. In hoeverre worden burgers gecompenseerd als ze willen overstappen op uw warmtenet? Bijvoorbeeld financieel, door het creëren van werk, door burger eigenaar te maken enzovoort.
   a. Helpt dit om bepaalde comfort barrières op te heffen?

Barrière 11 en 12
Renovatie en organize overkomen

8. In hoeverre worden burgers ontzorgd in uw warmtenet project bij het organiseren van de connectie van de woning op het warmtenet?
   a. Hoe worden burgers ontzorgd?
   b. Helpt dit om bepaalde barrières op te heffen? Zo ja welke barrières?

Barrière 7, 8, 9, 10, 12, 13, 14, 15, 17, 17 en 18
Heating, Controllability, Electric cooking, Health, Renovation, Price transparancy, Price comparability, Monopoly, Freedom of choice, Sustainability en Certainty of supply overkomen

9. In hoeverre worden burgers betrokken in het planningsproces van uw warmtenet?
    c. Op welke manier worden burgers betrokken?
    d. Helpt dit om bepaalde comfort en vertrouwens barrières op te heffen? Zo ja welke barrières.

Barrière 13, 14, 15, 16, 17 en 18
Price transparancy, Price comparability, Monopoly, Freedom of choice, Sustainability en Certainty of supply overkomen

10. In hoeverre zijn burgers eigenaar van uw warmtenet?
    a. In hoeverre helpt dit bij het overkomen van bepaalde vertrouwens barrières? Zo ja welke barrières?

Barrière 13 en 15
Price transparancy en monopoly overkomen

11. (Wss al gevraagd) Mag jullie bedrijf winst maken? Zo niet:
    a. In hoeverre helpt dit bij het overkomen van bepaalde vertrouwens barrières? Zo ja welke barrières?

Algemene vragen

5. Als u kijkt naar uw eigen organisatie. Denkt u dat uw organisatie voldoende in huis heeft qua financiën, kennis en kunde om warmtenetten te realiseren?
6. Als u kijkt naar organisaties waarmee u veel moet samenwerken. Bijvoorbeeld de gemeente, het burgerinitiatief en woning corporaties en warmtebedrijven. Denkt u dat zij voldoende in huis hebben qua financiën, kennis en kunde om warmtenetten te realiseren?
7. Ziet u nog contextuele factoren die de voortgang van warmtenetten in de weg zitten? (nationale wetgeving, de media, politiek enzovoort)
8. Als u drie dingen mag noemen die moeten veranderen om de warmtetransitie makkelijker te maken, wat zou er dan moeten veranderen?

Neutrale barrières (indien tijd over)

1. Op het lijstje van financiële barrières heeft u bij een aantal **neutraal** ingevuld. Kunt u aangeven waarom u neutraal heeft ingevuld?
   - Waarom is het wel/niet een barrière?
   - Hoe worden deze barrières overkomen?

Afsluiting:
Dit is het einde van het interview. Ik wil u nogmaals bedanken voor uw medewerking. Heeft u nog vragen?

Appendix 3 Code Tree

Deductive codes		
Group names financial barriers	**Barrier names**	**Potential strategies**
Connection costs	Connection costs	- Governmental subsidies
Investment costs	Investment costs	- Governmental loans - Building-bound financing - Increase mortgage
Lost investment costs	Lost investment costs	- Replace broken boiler
Network costs	1. Different network costs 2. High fixed network costs 3. Equal to gas price	- Collectively paid - Non-profit - Large-scale - Spread investment costs over time
Group names comfort barriers	**Barrier names**	**Potential strategies**
Heating	Heating	- Citizens engagement - Compensation - Experiencing
Controllability	Controllability	- Citizens Engagement - Compensation - Experiencing
Electric cooking	Electric cooking	- Citizens Engagement - Compensation - Experiencing
Health	Health	- Citizens Engagement - Compensation - Experiencing
Renovation	Renovation	- Citizens Engagement - Compensation - Unburdening
Organise	Organise	- Unburdening
Group names trust barriers	**Barrier names**	**Potential strategies**
Price transparency	1. Transparency price 2. Comparing prices	- Citizens engagement - Citizens ownership - Non-profit
Monopoly	1. Monopoly position 2. Freedom of choice	- Citizens engagement - Citizens ownership - Non-profit
Sustainability	Sustainability	- Citizens engagement - Citizens ownership
Certainty of supply	Certainty of supply	- Citizens engagement - Citizens ownership

Inductive codes
Barrier names
No choice between heating options
Outside nuisance
Potential strategies
Reduce renovation activities
Sale of a boiler
Lease of a boiler
Buy of a second-hand boiler
Social incentives

Appendix 4 Consent form

Onderzoeksvraag: Welke barrières beïnvloeden de deelname van burgers aan warmtenetten en hoe kunnen deze mogelijk worden overwonnen?
Verantwoordelijke onderzoeker: Ynske Sippens Groenewegen

In opdracht van Warmtestad en de Rijksuniversiteit Groningen schrijf ik een master thesis over de barrières die de deelname van burgers aan een warmtenet beïnvloeden. Hierbij wil ik onderzoeken welke barrières het grootste probleem zijn en hoe warmtenet projecten hiermee omgaan. Dit wil ik onderzoeken door experts te interviewen die een globaal beeld hebben van het verloop van warmtenet projecten in Nederland. Daarnaast wil ik een aantal stakeholders van warmtenet projecten interviewen om een gedetailleerder beeld te krijgen van het verloop van deze warmtenet projecten.

Deelnemers zullen worden geanonimiseerd. De functie van deelnemers in de organisatie zal worden genoemd mits de deelnemer hier toestemming voor geeft. De organisatie of het warmtenet project van de deelnemer zal wel in het onderzoek worden genoemd, omdat dit essentieel is om een beeld te krijgen van de kennis van de deelnemer en de karakteristieken van het warmtenet project.

Het interview zal worden opgenomen, zodat de onderzoeker deze kan analyseren. De onderzoeker zal ter inzage de conceptversie sturen naar de deelnemer. Als de deelnemer een opmerking heeft over de conceptversie, dan kan de deelnemer dit voor een nader te bepalen datum aangeven. Het onderzoek zal worden gedeeld met de master thesis begeleider, Warmtestad en mogelijk andere partijen.

In te vullen door de deelnemer
- Ik verklaar dat ik duidelijk ben ingelicht over de aard, methode en het doel van dit onderzoek. Het is voor mij helder dat de gegevens en resultaten van het onderzoek worden geanonimiseerd.
- Ik begrijp dat het opnamemateriaal uitsluitend voor de analyse van het interview zal worden gebruikt.
- Ik stem geheel vrijwillig in met deelname aan dit onderzoek. Ik behoud het recht om tijdens het interview mijn deelname aan dit onderzoek te beëindigen.
- Ik wil dat mijn functie binnen mijn organisatie wel/niet wordt genoemd in het onderzoek. *(Streep het foute antwoord door)*

Naam deelnemer: ……..

Datum: …… Handtekening deelnemer: ….....

In te vullen door de onderzoeker
Ik heb een mondelinge en schriftelijke toelichting gegeven over het onderzoek. Ik zal resterende vragen van de deelnemer beantwoorden. Er zullen voor de deelnemer geen nadelige gevolgen vastzitten aan het voortijdig beëindigen van het onderzoek.

Naam onderzoeker: …….

Datum: …… Handtekening onderzoeker: .....