DISTRICT HEATING SYSTEMS FOR SUSTAINABLE HEATING IN METROPOLITAN AREAS

HOW THE PLANNING & DESIGN OF DISTRICT HEATING SYSTEMS IN METROPOLITAN AREAS CAN SUPPORT STAKEHOLDERS IN THEIR TRANSITION TOWARDS SUSTAINABLE HEATING

A Qualitative Study on District Heating in Denmark and the Netherlands

S.V.H.J. Wiegerinck

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A Qualitative Study on District Heating in Denmark and the Netherlands

by

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Preface

What a beauty!
Or simply an eyesore, resembling the gloomy towers of the fictional world of Tolkien's Mordor?

The design of Erick van Egeraat's state-of-the-art *Energitårnet* waste incineration plant in Roskilde – of which a part of the interior is shown on the cover photo – can count on widely varying opinions like the above, ranging from loud applause to strongly disapproval. This more or less captures the range of views that apply to district heating. Like many other energy systems, district heating systems and the elements they consist of are often subject to far from sophisticated opinions and a public perception that regularly seems to be based on nothing more than gut feeling. Still, these systems play an important role in the energy sector of various countries and are expected to contribute to the transition towards more sustainable heating in many others.

For me, the great potential for the energy transition combined with confusion about definitions, the occasionally heated debate and the lack of knowledge and experience proved district heating systems would offer the right ingredients for a challenging thesis subject. I got exactly what I asked for. Over the course of many months, I dived deep into roles and factors, planning processes, greatly different stakeholders and an abundance of rules and regulations. It seems to me that district heating systems indeed offer a promising way to pursue a fully renewable heat provision. However, there still are so many uncertainties and problems to be solved. I think this research offers a modest, but relevant addition to existing knowledge and at the same time it shows the way to further improvements of the process through which district heating systems are planned and designed.

Although individually conducting research and writing a master's thesis can sometimes be a lonely activity, I did not go through this process all by myself. Many people have supported me, shared their knowledge, improved my understanding and also helped me relax and enjoy the time in between. Therefore, I want to thank all of the people that I met during this process and mention a few people in particular.

Naturally, I first would like to thank my graduation committee. Andy, Ivo and Thomas: thank you for your guidance, your eye for detail, your patience and for assisting me in shaping this research, while at the same time giving me the freedom to make it as ambitious as I wanted. Nico, thank you for your help in finding my way at Alliander, for brainstorming together, for keeping it light and making a joke on the side. I also would like to thank Daniel for offering me the opportunity to come to Denmark, hosting me at DTU and introducing me to the Danish context.

I cannot forget to thank the many people that took the time to let me interview them. I want to express my gratitude towards all twenty-three interviewees, both in Denmark and the Netherlands, who patiently explained me how the district heating sector works and were willing to think out-of-the-box, even being eager to learn themselves. Besides to them, I am also grateful to have informally deliberated and brainstormed with many other people, at places ranging from someone's living room to the national parliament.

Of course I would like to thank friends and family for being so supportive, offering to help or for simply talking about other things than insulated piping. During weeks I was not doing anything but writing about system requirements and other very inspiring matters, just drinking a beer or having a laugh was more valuable than they might have thought.

The last and – undoubtedly – the most important people I want to thank are my parents and Anna for being patient, worried, proud, calming and unconditionally supportive. My parents have always fully been there over the years, but even stepped it up during the last one. Anna: exactly that last year has not always been easy, which makes it even more wonderful that you managed to always help and encourage me and to make me laugh, especially when you did not feel like it. Many people have been helpful, but without you finishing this thesis would not have been possible.

I wanted a challenge and that is exactly what I got. I hope this thesis shows to be a proper answer to this challenge and all can enjoy reading the result!

Stijn Wiegerinck
Amsterdam, August 2020

Summary

Introduction

After the Paris Agreement of 2015 established the goal to hold the increase in global average temperature to well below 2°C above pre-industrial levels, it became clear that all sectors need to contribute. As heat accounted for 52% of global final energy consumption in 2015, of which roughly 40% was consumed in buildings, heating for the built environment is considered one of the most important sectors in the energy transition. As the majority of the world's population lives in buildings within cities and this percentage is rising, making the urban heating sector more sustainable makes for a huge challenge.

District heating (DH) systems offer an opportunity to overcome this challenge. However, the share of renewable heating is growing much more slowly than renewable electricity. Furthermore, it is not always clear how to appropriately design a DH system in order for it to support the transition towards a sustainable heat provision and to assist all stakeholders in this transition. What roles need to be fulfilled within the system and which factors influence the functioning of such a DH system? Also, how could the heat planning process and subsequent procurement procedure add to the design of DH systems that boost the heat transition?

Research methodology

The first research phase states the problem of interest and establishes a research strategy. This research addresses the problem as described above and in order to do so a research question and five sub-questions are drafted. The main research question is formulated as follows:

RQ	How could the planning process and system design of district heating systems in metropolitan areas support stakeholders in their transition towards a sustainable heat provision?

In the second research phase a literature review is conducted to study which roles need to be fulfilled within DH systems and what factors can be distinguished that influence DH system functioning. After careful preparation a multiple single-outcome study is performed on two cases: the DH systems of Greater Copenhagen and Greater Amsterdam. Through cross-case analysis the third research phase drafts stakeholder type descriptions, discussed their interests and influence and links these interests to system requirements. The fourth phase analyses the heat planning process of the two cases and defines system design types based on the factors from literature, which relate to the system requirements of the third phase. In the fifth and last phase improvements for the planning process and policy are identified, after which the implications and limitations of this research are discussed, followed by answering the research question and recommendations are made for dealing with the described problem and identified challenges.

Results

The literature study results show six main roles in and fifteen important factors of DH systems. These roles have to be distinguished from stakeholders, as a role can be fulfilled by different stakeholders and a stakeholder can perform multiple roles at the same time. The fifteen factors are divided over four categories; *technical*, *regulatory*, *economic* and *societal* factors. The case study results in two extensive case reports of Copenhagen and Amsterdam. Many differences and some similarities exist between the two cases, where differences mainly relate to historical development, physical dimensions, ownership structure and price regulation.

The cross-case analysis resulted in ten stakeholder types that were identified and for which interests in and influence on heat planning and DH systems were described. Of these ten, one half can be considered 'passive' stakeholders, the other half 'active' stakeholders. Especially the passive stakeholder types show a disbalance between interest and influence, which is considered to have an impact on the degree to which system requirements – on which tenders and system design options are based – represent the interests of these stakeholder types.

In the analysis of the planning process it becomes clear that stakeholder involvement in heat planning and in drafting system requirements in particular is limited. Especially the passive stakeholder group – consisting of consumers, housing associations, building owners and governments – are thought to be little involved and often also not properly (indirectly) represented in establishing the set of system requirements on which their DH system is based. The identification of technical and organisational system design types shows some configurations of choices on system design factors are less likely to come out of the planning, procurement and design processes, as passive stakeholder types – with interests that often differ from active stakeholder interests – are not included in drafting the system requirements on which these system designs are based.

The final chapter finishes by identifying potential improvements for the heat planning process, based on the mentioned challenges and problems.

Implications

The contributions and implications of this research are threefold: implications for science, for policy and for society are described. The scientific implications consider clear definitions of roles and factors, the description of the main stakeholders, their interests and their influence, the identification of planning challenges and the establishment of a descriptive framework for DH system design types.

The implications for policy either relate to the planning process, or to the legislative and regulatory framework. The finding of the fact that passive stakeholders are very little involved in drafting system requirements can have major implications for policymakers. Other implications of this research for the planning process relate to finding that the current planning and procurement processes do not incorporate the ability of DH systems to adapt to changing circumstances – which might be useful, given the energy transition that Europe is in. Other implications regard the possibility to increase transparency in tendering and tariffs, to mandate the establishment of guidelines for stakeholder involvement by local authorities and the possibility to allow for a wide range of system design configurations.

Lastly, societal implications regard – again – stakeholder involvement and citizen participation, increasing awareness of the possibilities and potential of DH systems and the identification of reasons for low or high societal support for DH systems in different countries.

Limitations

As every research process, this study is not perfect. Therefore, several limitations of the research exist. These relate to three categories: limitations of the research methodology that is applied, limitations of the data that is gathered and limitations of the results of the analyses and the generalisations that can or cannot be made.

The methodological limitations include the fact that the procedure used in the literature review limits the potential completeness of the identification of factors in DH system functioning. Also, the external validity of the methodology is under pressure because of the low number of cases and limited number of interviews, even though objective expert opinions were included and comparability was pursued. Via triangulation of sources the internal validity was improved and, even though verification and cross-checking of findings was not always possible, the validity and integrity of data as safeguarded, for example through recording and transcribing all 23 interviews that were conducted.

Regarding the data, limitations arise from the low availability of suitable cases and the sometimes difficult comparability of the two. The risk of a potential bias or an incentive to sugar-coat results might also limit the analysis of the data. The results that were found are mainly limited by constraints on the generalisation of these results, as only two cases and both within Europe limit conclusions and recommendations to be adopted outside of this research direct scope. Lastly, there is a risk that the results quickly become outdated, as the DH sector and the planning process are 'living' sectors and processes, especially now there seems to be momentum for DH systems as infrastructure for sustainable heating. Still, when policy and regulation regarding the planning process move in another direction, this research might even become more relevant over time.

Conclusion

In order to be able to answer the research question, several conclusions are drawn on the five sub-questions, based on the results and findings of this research.

Six separate main roles in DH systems exist, which do not have a fixed distribution over potential stakeholders, but are more or less free to be divided between parties or integrated within one. Furthermore, there are many different factors that have an influence on DH system functioning, not only the one or two that are discussed in isolation in some other research papers. Fifteen of these are identified and described, providing a basis for later analysis and answering succeeding questions.

Within the two studied cases, and probably generalisable for other European areas, it becomes clear there are ten important stakeholder types that each have their unique characteristics and personal interests. The influence of stakeholder types varies, but one group of passive stakeholder types shows a greater than average disbalance between interests and influence. This also has a significant impact on the system requirements that can be established, as the interests of these passive stakeholders are less well represented and incorporated.

The current heat planning processes in Denmark and the Netherlands show quite some similarities. In both countries involvement of all stakeholder types, especially of the passive group, is limited. This is an important challenge to the planning process, together with the fact that the planning and procurement processes do not properly incorporate the ability of the DH system to adapt to changes into the drafting of system requirements and especially in the evaluation of tenders.

Different DH system designs can be distinguished via a threefold approach that first defines what is a DH system and what is a 'regular' heating system, then establishes a technical design framework and lastly illustrates different configurations of the system's organisational design.

The answer to the last sub-question provides potential improvements for the planning process and regulation. Actively including all stakeholders has been found to be an important improvement, together with increasing transparency of the planning and procurement processes. These improvements show various potential benefits, like for societal support and citizen participation.

The answer to the main research question then concludes the research by acknowledging role distribution is not fixed, therefore leaving room for various system designs, as long as all stakeholder types are proportionally involved in establishing system requirements as last step of the planning process and towards realising a suitable design for DH systems that aim to support stakeholders in their transition towards sustainable heating.

Recommendations

Finally, several recommendations can be made, based on the findings, discussion and conclusion of this research. Some recommendations are considered generally applicable:

1. Incorporate adaptability of DH system design into planning and procurement
2. Include all stakeholder types in the planning process in general and the drafting of system requirements in particular
3. Increase transparency in the planning and procurement processes
4. Require local authorities to establish guidelines for stakeholder involvement in establishing requirements
5. Accept different system designs, based on the system requirements that are collectively established in heat planning

Other recommendations are case- or country-specific:

1. For Greater Copenhagen: reduce the dependency on CHP- and waste incineration plants that create a lock-in through the technical design
2. For the Netherlands: leave room for different system designs in the Heat Act that is currently being revised
3. For the Netherlands: establish a legal requirement in the *Warmtewet* to draft policies aimed at involvement of all stakeholder in drafting system requirements
4. For the Netherlands: consider the possibility to increase transparency of tariff, based on Danish experiences

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INTRODUCTION

Energy transition in the urban heating sector

By & Havn's *Svanemølleværket*, former CHP-plant, future Danish Museum of Science & Technology, Copenhagen

This first chapter introduces the context of the subject of this research. In section 1.1 the urban heat transition and its necessity is introduced, Section 1.2 follows by establishing the problem statement for this research. Lastly, section 1.3 briefly describes the role of Alliander as facilitator and host for this research.

1.1. Energy transition in the urban heating sector

Over the last decade the need for drastic measures in the global energy sector has become apparent. The worldwide debate accumulated in the 2015 Paris Agreement, which established a goal to hold the increase in global average temperature to well below 2°C above pre-industrial levels. Scientists, planners, policy makers and innovators generally agree that this is technically feasible (IRENA, 2018). Through both pursuing energy efficiency in all sectors and increasing the share of renewable energy in the total energy mix, this goal should be achieved. However, even as there is not much time to waste, opponents of this energy transition have made themselves heard over the last three years. Emission trends are currently not on track to meet the goal that was set in Paris (Plumer & Popovich, 2018).

To accelerate the energy transition all sectors have to contribute, from industry and the power sector to transportation and the built environment. As an increasing share of the world population is living in urban areas, cities have an immensely important role to play. Where around 35% of the world population lived in urban areas in the 1960's, this percentage increased to 55% in the last few years and is expected to keep rising (The World Bank, 2018).

Heat is the largest form of energy end-use and a significant contributor to global CO_2-emissions, accounting for 52% of global final energy consumption in 2015. Of this energy use, 60% of heat is consumed in industry and 40% in buildings (commercial and residential) (Collier, 2018, pp. 4, 7). As heat is primarily produced with fossil energy sources and a significant share of heat is lost in transmission, storage and a lack of insulation, there is huge potential for energy saving and increasing the share of renewable energy. In the European Union and the United States – two of the world's three largest heat consumers, together with China – most of the heat demand occurred in buildings, with 59% and 54% respectively (Collier, 2018, pp. 8-9). Given the risen urbanization, currently at 75% in the European Union and 82% in the United States, perhaps the most significant challenge in the energy transition for the Western World is therefore in making the urban heat sector more sustainable.

A way to meet this challenge could be by using district heating systems (DH systems), which are – generally speaking – energy systems that, through insulated pipes, distribute hot water to many different buildings in a city or town. District heating systems can potentially contribute considerably to energy savings and can serve as suitable infrastructure for integrating renewable energy sources into the urban heating system, especially in dense urban areas (Surmeli Anac, Grözinger, van Tilburg, & Offerman, 2016, p. 8). Particularly in large and dense cities with a high heat demand density, district heating systems could play an important role, due to the lower average fixed costs (IRENA, 2017, p. 37) and lower energy losses in transmission compared to less dense cities. DH systems are well-established and already widely used throughout the world. In Europe there are around 6,000 district heating and cooling networks (Surmeli Anac, Grözinger, van Tilburg, & Offerman, 2016, p. 8). However, this does not necessarily mean that these networks always operate in a very sustainable way and are future-proof.

Furthermore, existing district heating systems and technology are facing challenges in terms of integration of renewable (low-temperature) heat sources, energy dependency, costs and efficiency. As many DH systems are vertically integrated and thus owned and operated by the only energy provider in the network (a monopolist), there also have been discussions in several countries about the organisation of these systems and on ways to increase competition, in order to decrease energy prices and create the possibility to select a heat supplier according to the consumer's preferences (Pöyry Management Consulting Oy, 2018, p. 6) (Kamp, Kamerbrief Warmtevisie, 2017, pp. 21-22). Besides this, current systems often do not use sustainable energy sources, with coal, natural gas and (fossil-based) waste heat as significant unsustainable sources and only a few countries with a significant share of biomass in their DH systems (IRENA, 2017, p. 20).

Opportunities for DH systems can also be found in the rising share of renewable power generation in many countries (Surmeli Anac, Grözinger, van Tilburg, & Offerman, 2016, pp. 49-50). The share of (intermittent) renewable electricity is expected to rise significantly, for instance in the Netherlands from 8% currently to around 50% in 2025 and around 65% in 2030 (Schoots, Hekkenberg, & Hammingh, 2017, p. 120). The intermittent nature of sources like wind and solar creates a need for storage in order to offset the peaks in power production and keep the electricity grid stable. For example creating opportunities for storage in DH systems could benefit both the electricity and the district heating sector. Other 'sustainable' opportunities are to integrate renewable (thermal) energy sources like geothermal energy, wastewater, surface water or (non-fossil) waste heat. Especially geothermal energy shows great potential, although it has a long way till it can be considered a mature technology that is ready to be deployed on a large scale. In the Netherlands, geothermal energy is researched by several universities, research institutes and other public and private parties, like the state-owned Energie Beheer Nederland (EBN) research company (Energie Beheer Nederland B.V., 2018).

Instead of debating if a fully centralised approach (current DH systems with one or a few large-scale (fossil) sources) or an entirely decentralised approach (individual building level solutions like small heat pumps) is the key to a sustainable heating system, the discussion could also be focused on different options for the design of DH systems. The possibility to configurate different aspects of a DH system in such a way it is suited to the local needs could not only better adjust the system to stakeholder preferences, but could also stimulate innovation and competition in the heating sector (Pöyry Management Consulting Oy, 2018, p. 6).

To both tackle the challenges for and utilize the opportunities of DH systems, different actors are increasingly looking at and deliberating on factors like decentralisation of (renewable) heat production, third-party access (TPA) for producers and/or retailers, unbundling of network (distribution) activities from production (and from retailing), different forms of price regulation and many others (Li & Wang, 2014, p. 1474) (Kamp, Kamerbrief Warmtevisie, 2017, pp. 21-22) (Söderholm & Wårell, 2011, pp. 743-751). These concepts may lead to DH systems opening up to multiple parties, allowing a diversification of energy sources, introducing competition or lowering prices. In the Netherlands the debate has also been focused on 'opening up' of DH systems to multiple producers or even multiple providers, which has been spread in policy papers, research and the public debate. "Opening up" is quite an abstract term that refers to the closed character of the current DH systems, with privately owned and vertically integrated monopolists in many areas (Ecofys, 2015, p. 2). However, there may also be disadvantages when these ideas are implemented incorrectly or unnecessarily. Furthermore, whether a renewable heat source is economically viable or if introducing TPA is efficient also depends very much on the specific (physical) situation that the DH systems is in. Next to that, there are other heating technologies competing with DH.

Many questions still remain and different actors approach these questions from their perspective and expertise, mainly taking their individual interests into account, subconsciously or not. There are also large differences between DH systems in terms of size, (heating) density or current pricing strategy that influence the impact of a certain approach (Söderholm & Wårell, 2011, pp. 748-751). New research should therefore adopt a more integral and multidisciplinary approach to the planning and design of DH systems.

1.2. Problem statement

Governments throughout the world are setting more and more ambitious climate agenda's. Cities and their governments, citizens and businesses can play an important role in the energy transition, as around 60% of global energy demand in 2014 came from inner-city transport and residential and commercial buildings in cities (IRENA, 2016, p. 37). Between 2010 and 2015 renewable electricity generation grew by 31%, where renewable heat (including renewable electricity used for heating) only grew by 12% in the same period, accounting for only 9% of global heat consumption in 2015 (Collier, 2018, p. 4). Although there is a lot going on in establishing a more sustainable electricity sector, the heating sector is possibly even more important, as the largest share of energy demand in cities in colder climates comes from heating (see Figure 1).

Looking at Figure 1 it becomes clear that in densely populated cities in cold climates the share of energy used for heating is by far the largest. The absolute energy use per capita for heating is relatively stable when population density is rising, in contrast to cooling, electricity and transport. This would mean that the so called heating demand density, which is the amount of (heating) energy demanded per km^2, is higher in densely populated cities. Heating demand density is one of the most important parameters for the feasibility of district heating systems (IRENA, 2016, p. 19), therefore DH systems are expected to generally be better feasible in cities with higher population density.

There are many potential benefits of district heating and the introduction and expansion of renewables in DH systems in dense cities. Besides the obvious environmental benefits, there are systemic benefits like the use of local resources, cross-sectoral benefits and economies of scale. Furthermore, DH systems can enhance energy security (if sources are diversified) and create synergies with the existing urban environment (IRENA, 2017, pp. 13-15). Therefore, it is not surprising that many Western European national governments aim to increase the share of DH – following the Northern European countries that did so decades ago – and several municipalities are already expanding existing or constructing new DH systems (Surmeli Anac, Grözinger, van Tilburg, & Offerman, 2016, p. 10). However, it is not always clear how DH systems need to be designed in order to realise these benefits. This is for example shown in the transition away from natural gas for domestic heating in the Netherlands, where municipalities face a lack of knowledge and confusion about the range of possibilities in the DH system design and the planning and design processes (Tigchelaar, Winters, Janssen, Huygen, & Brus, 2019, pp. 7-8).

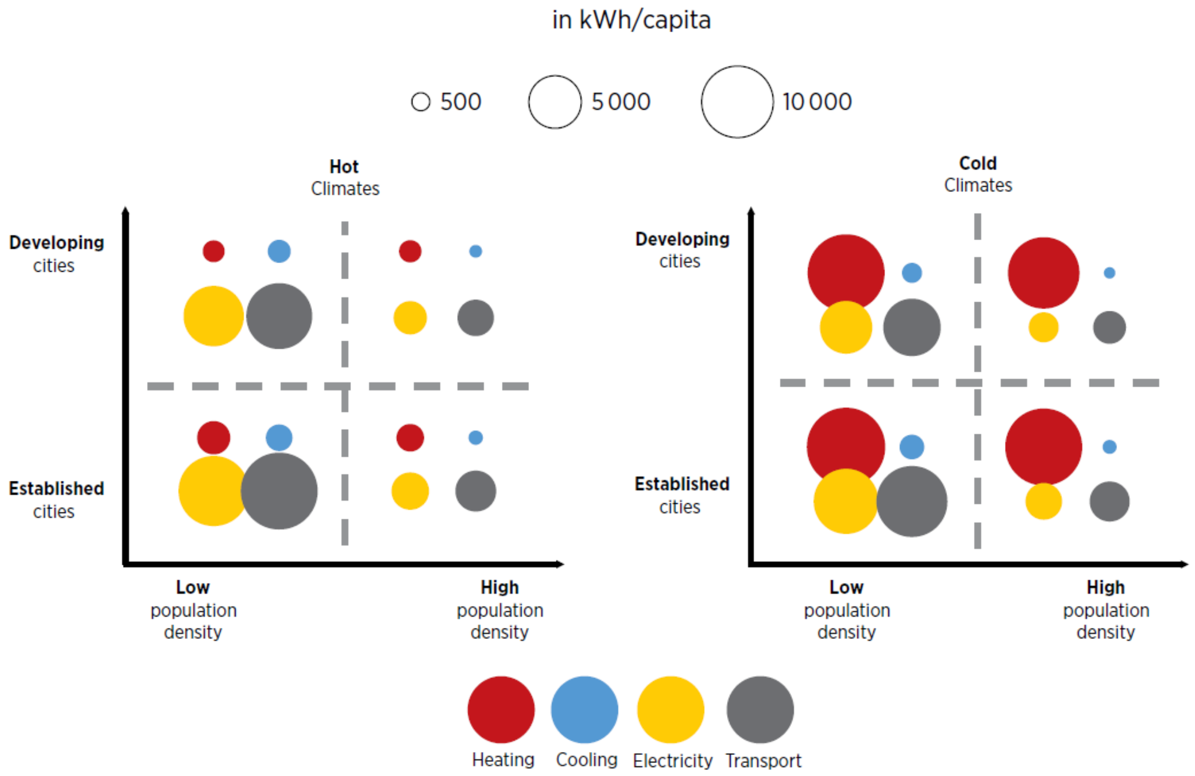


Figure 1 – Energy use in cities (in 2014), separated in developing and established cities in hot and cold climates (IRENA, 2016).

Although DH systems could contribute to dealing with the mentioned challenges and opportunities in the urban heating sector, this requires a different system design compared to current DH systems. The design of new DH systems and expansion or modification of existing DH systems should be adapted to the future energy system and expected demands (Lund, et al., 2014, p. 1). However, as there is a wide variety of DH system designs, reaching the appropriate system design for the given context can be complex. In fact, it sometimes is not even clear what is understood when talking about a 'district heating system'. There are various factors that influence the functioning of a DH system. Some of these factors might be related to design choices that actors make and thus define the system's design.

Nevertheless, a clear overview of these factors is not available and, consequently, there seems to be no proper understanding of the different ways DH systems can be designed, both technically and organisationally. Moreover, the impact of these different designs on the degree of fulfilment of the interests of stakeholders in the (future) DH system is often uncertain. Therefore, it can be difficult for municipalities and other stakeholders to assess the potential benefits, required policy and the technical and economic feasibility of a certain system design for their area or city. It is thus often unclear how a DH system could be or needs to be designed in order to increase the share of renewable heat in a certain area.

Lastly, the degree and way of involvement of stakeholders in the process of selecting heating technologies and designing (collective) heating systems can differ significantly between areas (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016). It is often considered important to involve all stakeholders in the decision making process on DH systems and the heat planning process that precedes it (Tigchelaar, Winters, Janssen, Huygen, & Brus, 2019, pp. 16-17). Alignment of interests of different stakeholders and especially consumer involvement are considered key success factors in realising DH systems. However, this involvement is not always properly embedded in heat planning processes. For example in the Netherlands stakeholders (especially consumers) are not actively involved in the heat planning process and also not in the design of the system itself. Municipalities, being the designated party to coordinate the heat transition in the Netherlands, often do not know how to properly engage citizens and other stakeholders (Tigchelaar, Winters, Janssen, Huygen, & Brus, 2019, pp. 16-17). This example shows the need to not only focus on the DH system's design and its ability to increase the share of renewable heat, but also on how the heat planning process can support reaching the appropriate DH system for a given area.

1.3. Role of Alliander

This research project is performed as part of the study programme of the Master of Science (MSc.) in *Construction Management and Engineering* at Delft University of Technology. Academic standards are considered vital for successful completion of the study programme, therefore independency from interests of third parties is important in conducting this research. As the subject of the study is considered to be highly relevant for society, given the ongoing and invasive energy transition, the research project is carried out at Alliander N.V. The energy network company Alliander is a publicly owned distribution system operator for electricity and gas networks in the Netherlands, with 3.1 million and 2.5 million connections respectively, both residential and commercial/institutional (Liander N.V., 2019). Alliander is mainly active in the provinces of Noord-Holland, Gelderland, Friesland and Flevoland. Through its subsidiaries Firan (development, financing, operation) and Qirion (engineering & consultancy and maintenance) Alliander is also active in (district) heating systems.

However, there is currently not a clear role for Alliander in the district heating sector and unlike electricity and gas, network operation is not a task that is legally assigned to Alliander. Therefore Alliander is, like many other actors in the heating industry, interested in the theory behind the role of district heating systems in the transition towards renewable heating for the built environment, the different system designs, the planning process and the development of district heating in the Netherlands in the coming years. Although the expertise on energy systems, the contacts and the resources Alliander has to offer can be used for this study, the research is independent from Alliander's individual interests and the researcher has no obligations towards Alliander. This report is also freely available and can be read by anyone that is interested in the planning process and the design of district heating systems in urban areas.

2

RESEARCH DESIGN

Qualitative research, literature review and cross-case analysis

AEB's waste incineration plant, Amsterdam

The introduction and problem definition in the first chapter provide a brief overview of the status quo in the urban heating sector and the challenges and opportunities that lie ahead. In order to develop a proper research plan and design a suitable approach, a clear objective is formulated in section 2.1. After drafting a research question that addresses the research problem and corresponding objective, a set of subsequent sub-questions is described, both in section 2.2. The scope for this research is carefully determined in section 2.3, the relevance of this research project is illustrated in section 2.4 and finally the research strategy is tuned to answer the questions and meet the objective, given in section 2.5.

2.1. Research objective

This research will contribute to the energy transition in the heating sector. More specifically it provides insight on the different possibilities in DH system design and the impact design choices have on the interests of stakeholders in that system. It will also shed light on the way the heat planning process can support stakeholders in their transition towards renewable heating in urban areas. This is relevant for academics, policy makers and societal actors like citizens and businesses, as will be explained in section 2.4. Given the defined problem in the previous chapter, the research objective is described as follows:

"To explain how the planning process and the design of a district heating system can contribute to the transition towards sustainable heating for metropolitan areas."

2.2. Research questions

Resulting from the problem definition and objective in sections 1.2 and 2.1, the following research question is derived:

RQ	How could the planning process and system design of district heating systems in metropolitan areas support stakeholders in their transition towards a sustainable heat provision?

This main question will be answered in stages in order to fully answer the question. This results in five sub-questions, each covering a different aspect of the main research question. The five questions below are drafted to capture every element of the research question, without overlapping each other. Section 2.3 illustrates the scope, within which these questions are applied. Section 2.5 explains the research strategy that is adopted to answer these questions.

SQ1	What are factors in the functioning of district heating systems and which roles can be distinguished in existing literature?
SQ2	What are the characteristics, interests and influence of the main stakeholders in a district heating system in a metropolitan area and what are the resulting requirements towards the system?
SQ3	How are district heating systems currently planned by stakeholders in metropolitan areas and what are the main challenges?
SQ4	What are possible district heating system design types and how do these relate to stakeholder interests and system requirements?
SQ5	What improvements can be made in the planning process of district heating systems in metropolitan areas, to support stakeholders in their transition towards a sustainable heat provision?

2.3. Research scope

In order to be able to properly execute the research, a clear scope has to be defined that both sets boundaries and indicates what aspects of the research problem deserve specific attention. In general, the research concentrates on the planning process and the (technical and organisational) design of DH systems in European metropolitan areas. This general and brief description will be explained more extensively by elaborating on the different aspects in it.

2.3.1. Sustainability of heat provision

Where other studies often focus on economic optimisation of DH systems (Söderholm & Wårell, 2011) (Wissner, 2014), on the role of DH systems in a renewable heat supply, compared to other technologies (Lund, Möller, Mathiesen, & Dyrelund, 2010) or on the impact of a specific design or regulatory factor on the sustainability of a DH system (Sacchi & Ramsheva, 2017), this research focuses on impact of DH system design choices on the sustainability of the metropolitan heat provision. It also looks into the way the heat planning process can support all stakeholders in realising a renewable heat supply. Naturally other public goals and stakeholder interests like affordability and reliability of the system are taken into account, but emphasis is on the way the system design and planning process can support stakeholders in their transition towards sustainable heating.

2.3.2. Design of district heating systems and the planning process

The research has a twofold focus: it looks at the design of the DH system and the heat planning process of DH systems. When discussing the system's design, both the physical design and the organisational design of the system are considered. Furthermore, the regulatory and policy framework is also taken into account, as it could have significant impact on whether or not the DH system meets the interests of its stakeholders. Besides the system's design itself, the research also looks at the heat planning processes that precede the procurement, design, construction and operation of the DH system. This ranges from initial orientation and discussions about the choice for a certain heating technology – either individual or collective – for an area, to the establishment of system requirements that follows the possible choice for a DH system. The planning process is considered to end at the establishment of a set of system requirement, based on which potential DH companies can draft their proposal and, after selecting a company through public procurement, the DH system is designed and constructed.

2.3.3. Metropolitan areas

The challenges and opportunities for DH systems discussed in section 1.1 need to be dealt with. As DH systems are most likely to be successful in distributing (renewable) heat in an efficient and reliable way when applied in dense urban areas with a significant heat demand density, this research will focus on cities that satisfy this criterium. By studying DH systems in large cities or metropolitan areas, both a high heat demand density (HDD) and a variety of neighbourhoods and building types are expected.

In order to do this, metropolitan areas are defined as a "functional urban area" with a population between 500,000 and 1.5 million people, a large metropolitan area would have a functional urban area with a population above 1.5 million people. A functional urban area is an urban area composed of densely inhabited urban core(s) and hinterland. An urban core consists of highly densely populated contiguous municipalities, where the (urban) hinterland consists of municipalities connected to the urban core by having a certain share of their employed residents working in the urban core (OECD, 2012, pp. 14-15). For example, with this OECD definition the city of Amsterdam would qualify as a *large metropolitan area*, given the approximately 860,000 people that live in the municipality of Amsterdam in 2019 (CBS Statline, 2019) and the 2,717,363 people that are included in the Amsterdam metropolitan area in 2016, according to the OECD statistics (OECD, 2019) (OECD, 2012). In this research the definition of a metropolitan area and large metropolitan area will be according to this OECD standard, so with a minimum of 500,000 and 1,500,000 inhabitants of the functional urban area respectively.

2.3.4. European heating sector

Europe and the United States (US) see that the majority of their total heat demand is used to heat buildings (Collier, 2018, pp. 8-9). The share of renewable heat in the total heat consumption in the US was around 10% in 2015, which was roughly the global average. In the Netherlands, this share was around 6%, well below the global average. Other European countries had higher shares of renewable heat, with the Nordic countries being in the lead, varying from 40% (Denmark) to 53% (Finland) and even 69% (Sweden). These countries also have extensive district heating networks, which are thought to be able to facilitate in increasing the share of renewable heat (Collier, 2018, pp. 20-41).

Because the US and Europe are highly urbanised, both are facing challenges in making their urban heat supply more sustainable. Cities in Europe and large parts of the US are often densely built and already well developed. However, the most significant developments in the DH sector seem to take place in Europe, especially in the Northern and Western European countries and much less in the United States (Tredinnick, 2013). These parts of Europe also have a relatively high heat demand density, have a relatively cold climate and are therefore interesting for research on district heating. Not only the maturity of the DH sector differs significantly between the Northern and Western European countries, there is also quite some variation in their regulation and policy frameworks. In order to address the challenges for cities in these regions and be able to learn from differences in technologies, policy and market development, this research will focus on the DH sectors and associated technical, policy and economic context of Northern and Western Europe, as defined by the Publications Office of the European Union (European Union, 2019).

2.4. Relevance of research

This research project is relevant on three levels. Naturally, there needs to be a scientific relevance for an academic thesis. Besides this, there is also a relevance for policy-makers. Finally, there is a societal relevance, as there are useful insights for different stakeholders in the heating sector.

2.4.1. Scientific relevance

Whether DH is a suitable technology for a certain area and how the system needs to be designed and organised depends on many different criteria. Which possible benefits will be attained by a DH system design is influenced by a combination of factors and the context this combination is applied to. In earlier studies, researchers often focus on the impact that one certain design factor or policy tool has on the operation and performance of the DH system.

Furthermore, in assessing this impact they also generally focus on one of the three public goals of affordability, reliability and sustainability, not on all three. Usually, the impact on economic efficiency is studied. Lastly, most studies do not focus on the DH system's design in a specific physical context, like dense urban areas or remote small towns.

The knowledge gap in current literature consists of a few aspects that are briefly outlined below. Earlier studies do not:

- *Specifically focus on metropolitan areas, with a high heat demand density.* As Söderholm & Wårell (2011, p. 751) concluded, there for example is a need for future research to focus on specific networks when studying the impact of opening DH systems up for competition. The best conditions for third-party access (TPA) are likely to exist in larger metropolitan areas (Söderholm & Wårell, 2011, p. 744). Besides the size of the area in terms of total demand, the heat demand density (HDD) of an area is also important to assess the viability of the network. Generally, a minimum level of HDD is required for a viable DH business case (IRENA, 2016, p. 19). Therefore, concentrating on areas with a certain minimum annual heat demand (in TJ/year or GWh/year) and a minimum HDD could lead to different and perhaps more relevant conclusions for the choices that need to be made for DH system organisation in these metropolitan areas.
- *Combine different factors, like the possibility of TPA – for both producers and retailers – with the option for unbundling, the temperature regime or the choice for public or private network ownership.* Other studies often specifically focus on one factor, like TPA (Söderholm & Wårell, 2011), price regulation (Sacchi & Ramsheva, 2017) or public and private ownership (Magnusson, 2016). And for example unbundling is not often researched specifically for district heating, like it is done by Tieben and Van Benthem (2018), but is mostly researched for other energy infrastructures like for the power sector (Gugler, Rammerstorfer, & Schmitt, 2013) or for energy transmission in general (Pollitt, 2008). This study will have a wider scope in terms of elements that influence the DH system's functioning and will identify the most important factors.
- *Focus on DH systems that are yet to be built, so not (only) on currently existing systems.* Studies on DH mainly look at functioning of current systems or impact of changes in regulation on existing DH networks (Söderholm & Wårell, 2011) (Pöyry Management Consulting Oy, 2018). As DH systems are considered to offer opportunities for shifting to higher shares of renewable heating, new systems are to be developed on a large scale. Focusing on the way new DH systems should be designed in order to contribute to the heat transition is therefore expected to have a significant impact.
- *Search for a DH system design as a mean to support the transition to a renewable heat supply.* Most studies focus on optimising economic efficiency in DH systems (Söderholm & Wårell, 2011) (Wissner, 2014), seem to prioritise affordability over sustainability (Tieben & Van Benthem, 2018) or they study the impact of only one very specific measure on sustainability, like influence of legal and economic constraints on carbon footprint reduction through industrial excess heat delivery in DH networks (Sacchi & Ramsheva, 2017). This research aims to zoom in on the relationship between the system's design and the degree it is able to support stakeholders in the transition towards a sustainable heat supply.

This research addresses these knowledge gaps in scientific literature by studying how the design and organisation of DH systems for metropolitan areas can stimulate the transition to a sustainable heat supply.

2.4.2. Policy relevance

In many countries, especially in (Northern and Eastern) Europe, DH is an important technology for the energy supply in the built environment (Wissner, 2014, p. 63) (Söderholm & Wårell, 2011, p. 742) (Werner, 2017) (Sacchi & Ramsheva, 2017, p. 41) (Sandberg, Sneum, & Trømborg, 2018, p. 105). Governments, both local and national, play and have played an important role in realising and creating frameworks for DH systems. National governments can establish climate policies that may drive DH development (Werner, 2017, p. 425) and they can introduce legislation, either in general for the energy sector or specific legislation for DH (Werner, 2017, p. 426). Furthermore, municipalities are often seen as driving forces or even developers of DH systems (Magnusson, 2012, p. 449), especially in countries (or times) where other energy systems – like electricity – were also publicly owned (Werner, 2017, p. 425). Especially municipalities and other local authorities are mentioned as very important parties in the urban heating transition (Weiβ, Dunkelberg, & Hirschl, 2018). *"In Denmark municipalities are the central players in the collective heating supply"*, according to the Danish Energy Agency. They are responsible for municipal heat planning and strive for the heating form with the largest net benefits to society, aim to stimulate environmentally friendly heating and reduce the dependency of fossil fuels (Danish Energy Agency, 2017, p. 15).

The Dutch national government aims for a neighbourhood-level approach in the shift away from the use of natural gas in residential heating, where the municipality has a leading and coordinating role (Rijksoverheid, 2019, pp. 23-31)

(Hoogervorst, 2017, pp. 49-50). Municipalities are even considered to not only be the appropriate organisation to orchestrate this transition to sustainable heating, but also to decide over the infrastructure that is suitable for the area and needs to be constructed and possibly also to appoint a party for construction and the exploitation (Tieben & Van Benthem, 2018, p. 9).

However, municipalities not always have much actual 'power'. In Sweden municipalities have less practical power than they used to have, because of changed planning legislation, liberalisation and stronger private actors in the heating sector (Magnusson, 2012, p. 454). In the Netherlands, a recent study on difficulties that municipalities face in this heating transition (specifically with district heating) concluded that municipalities feel they are not (yet) capable of realising the heating transition. This is because of confusion about their role, lack of authority, insufficient financial means (Natuur & Milieu, 2018, p. 9), little transparency and dependency on a few powerful market players (Tigchelaar, Winters, Janssen, Huygen, & Brus, 2019, pp. 12, 21-23). Still there are many municipalities with ambitions for a sustainable (district) heating sector (Natuur & Milieu, 2018, p. 10), sometimes as strong as realising a fully carbon neutral district heating sector in 2025 (City of Copenhagen, 2012, p. 14).

Having a more clear overview of DH system design options, with the sustainability of the heat supply in mind, will help national and local policy makers to stimulate the heat transition in urban areas. It is the responsibility for national governments to shape the right policies to enable local governments in realising this transition. In doing this, DH is not a goal in itself, it is merely a tool for reaching societal goals like sustainability in energy provision (Werner, 2017, p. 425). This study contributes to these challenges for policymakers by studying what influence different system design types have on public goals – and especially on realising climate and energy goals in the light of the heat transition in many countries. This research is also relevant for policy makers and legislators, as it identifies aspects that policy and regulation need to take into account and make suggestions for policy decisions. It also evaluates current heat planning and system design practices and looks into ways the planning process can support and include (all) stakeholders in the establishment of requirements for a DH system.

2.4.3. Societal relevance

Besides this study's scientific and policy relevance, the outcomes are also expected to be relevant from a societal point of view. The *Netherlands Environmental Assessment Agency* (PBL) expects an increase of the use of district heating to almost 60% of the heat supply for residential buildings, if taxes on natural gas are increased to €1.50 per m^2 in 2050 (Hoogervorst, 2017, p. 44). To persuade citizens to replace their natural gas connection with a connection to the DH system, the PBL thinks the national government should stimulate the development of sustainable district heating systems, as citizens are expected to be more inclined to switch when they know they're building a future-proof energy system (Hoogervorst, 2017, p. 15). Studying how the DH system's design impacts the sustainability performance and at the same time secures an affordable and reliable heat supply is therefore very relevant – if not crucial – for society.

The planning process and involvement of different stakeholders in the heating sector is also very important. As the PBL states, it is also important for citizens to be informed early in the planning process in order to anticipate on expected changes in their energy provision. Involving citizens in the planning process could also increase the support for DH systems (Hoogervorst, 2017, pp. 49-50), as is for example shown by research on Danish onshore wind energy projects (Rønne & Nielsen, 2019, p. 240) (Borch, Nyborg, Clausen, & Jorgensen, 2017). The Dutch national government aims to involve stakeholders in general and citizens in particular in the energy transition, mainly to realise broad support (Rijksoverheid, 2019, pp. 216-219). Research that focuses on the way the planning process for (district) heating systems therefore also has societal relevance.

2.5. Research strategy

This section describes the strategy that is applied to answer the research questions in this study. The research process consists of five main phases, followed by the finalisation. Each of these phases is briefly introduced.

The research strategy is presented in Figure 2. In the figure each of the phases is illustrated schematically and consists of one, two or three research steps. For each research step the applied research methods are given. Every research step is executed and described in a separate chapter of this report. Lastly, the output that arises from all phases are outlined on the bottom of the figure.

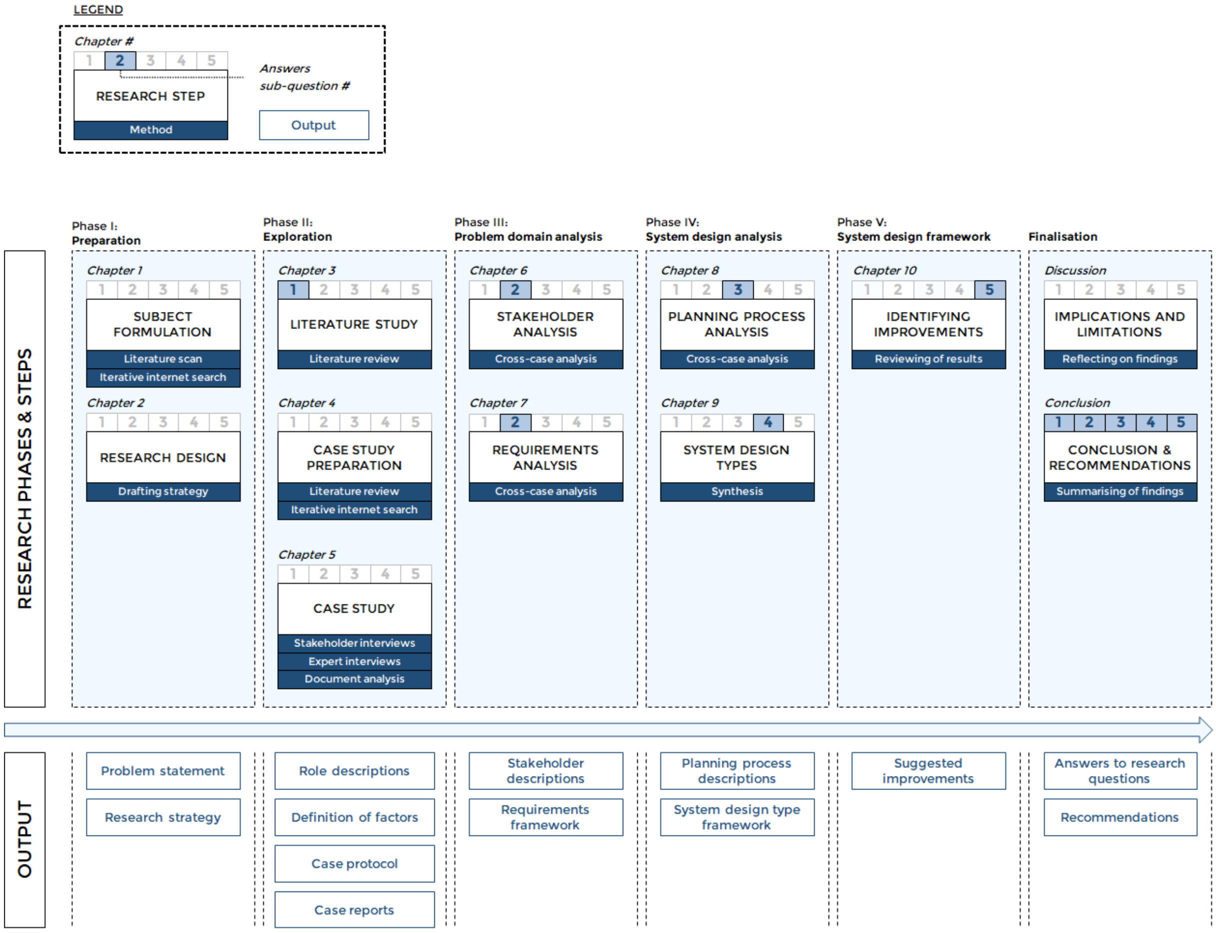


Figure 2 – Schematic representation of the research strategy, illustrating different research steps, phases, methods and output (own illustration)

2.5.1. Phase I: Preparation

The first research phase consists of two steps. By scanning available literature and iterative internet searching the subject for this study is refined and formulated in section 1.1. Besides providing a condensed but thorough introduction to the subject, this step also presents the problem statement for further research in section 1.2. In the second step the problem statement is translated into a research objective in section 2.1, followed by one main research question and five sub-questions in section 2.2. The research scope is outlined in four parts, covered in section 2.3. Section illustrates the relevance of this research on the scientific, policy and societal level. Lastly, the strategy that is applied to perform this research process is described here, in section 2.5. The main output of *Phase I* consists of the problem statement of chapter 1 and research strategy of chapter 2.

2.5.2. Phase II: Exploration

The main goal of the second phase is to further explore the research field and gather relevant data. This data is primarily gathered through literature review, stakeholder interviews, expert interviews and document analysis. The first research step of this second phase aims to answer the first sub-question, which focuses on the roles that are fulfilled in DH systems and the factors that determine DH system functioning. Relevant literature is predominantly retrieved via *Google Scholar* and *Scopus* and to a lesser extent via the *TU Delft Repository*. To study DH system factors in section 3.2 directed search terms are employed first, followed by a snowball sampling strategy that builds on preliminary findings and aims for a very broad representation of relevant factors. In describing the roles in DH systems in section 3.1, the literature review builds on a smaller range of research papers and reports, where the description of roles in DH in the report by Tieben & Van Benthem acts as the starting point (2018, pp. 5-6).

After this literature study, the case studies are prepared for in the second step of this research phase. Chapter 4 describes the procedure for the selection of the cases (section 4.1), data gathering (4.2), the selection of stakeholder and expert interview participants (4.3), the case protocol (4.4) and the handling and analysis of the collected data (4.5). This case study procedure builds on literature on case study research, qualitative research methods and data analysis.

The third research step of *Phase II* is about performing the case studies; through conducting interviews with selected stakeholders and independent experts in the DH sector of the case and through analysis of documents that cover aspects of the DH system. These interviews will adopt a *semi-structured* approach, which will be further elaborated upon in chapter 4. The case studies result in two extensive case reports that cover the current DH system(s) in the selected cases, the historical development, the regulatory framework, economic parameters and future challenges. This research step, presented in chapter 5, concludes with a cross-case overview of selected characteristics of both cases.

2.5.3. Phase III: Problem domain analysis

Based on the empirical research of the case studies the two research steps of *Phase III*, as presented in chapter 6 and 7, conduct a stakeholder analysis and requirements analysis respectively. Through cross-case analysis different stakeholders are identified and described in section 6.1. Their interests in a DH system and their influence on the system's design are also thoroughly described in section 6.2 and compared using a power-interests grid in 6.3.

The next step focuses on identifying possible requirements towards the DH system that result from the case studies through cross-case analysis. In section 7.1 these requirements are briefly described, in section 7.2 their relationship to the stakeholder interests are illustrated, based on the stakeholder and expert interviews in the selected cases. Together, chapter 6 and 7 answer the second sub-question.

2.5.4. Phase IV: System design analysis

The fourth phase focuses on the heat planning process and the influence it has on the system design. Through cross-case analysis of the case study results the heat planning processes of the cases are compared in chapter 8 and emphasis is on the weaknesses within these processes. This answers sub-question 3, which aims to describe the current planning process of DH in metropolitan areas and to identify the main challenges in realising a DH system design that is able to support its stakeholders in their heat transition.

The second step of *Phase IV* identifies a selection of the factors that were described in section 3.2 as system design factors that influence the DH system's design. Through synthesis of these different factors a framework is established that distinguishes system design types. Then, these design types and the factors that constitute them are coupled to the requirements that were identified in chapter 7. This way the fourth sub-question is answered, covering system design types and their relationship with stakeholder interests and requirements.

2.5.5. Phase V: System design framework

The last research phase consists of only one step, presented in chapter 10. Through careful review of the results of chapters 6, 7, 8 and 9 existing challenges and potential improvements of the district heating system planning process are identified in section 10.1. Besides these suggested improvements, a small number of specific considerations regarding the regulatory framework are provided in section 10.2.

2.5.6. Finalisation

Lastly, the research is finalised by reflecting on the findings in earlier phases and chapters, summarising these findings, answering the main research question and, in doing so, concluding the research. First, reflecting on these findings results in a discussion of the implications and limitations of this research. There can be scientific implications, societal implications and implications for policy and regulation. Furthermore, the limitations of this study can for example range from constraints due to the adopted research methodology, from the data gathering and analysis and from the degree to which the results and findings can be generalised.

The last chapter of this research report covers the conclusion, in which the answers to the five sub-questions are summarised and, through those sub-questions, the main research question is answered. Also, based on this research several recommendations are drafted. This chapter is completed with suggestions for further research.

3

LITERATURE STUDY

District heating system roles and factors

HOFOR's *Amagerværket* CHP-plant, Copenhagen

District heating has become a widely discussed and intensively studied subject. Over the years, numerous academics have conducted research on the subject, resulting in many scientific papers and conference articles. This chapter will answer the first sub-question by reviewing the available literature.

SQ1	What are factors in the functioning of district heating systems and which roles can be distinguished in existing literature?

The different roles that actors in DH systems can fulfil are studied and described in section 3.1. Furthermore, in section 3.2 the factors that shape DH systems are studied, in order to provide a solid base for describing and categorising DH systems in the following chapters.

3.1. Roles in district heating systems

There are many stakeholders in and around DH systems. Some parties play an active role in DH systems, others are more passively participating or are potential stakeholders, but not yet involved at all. Within DH systems, there are several roles to be fulfilled. In this report, we distinguish a role from a stakeholder. Stakeholders can fulfil one single role, multiple roles at the same time, or no role (yet). Based on the literature review, six main roles are distinguished that are actively involved in a DH system and influence the way the system functions on a daily basis. Some other roles that have a more passive task are also briefly introduced. These six roles are defined because the distribution of these roles over different stakeholders is very relevant to the way a DH system functions. Furthermore, in current academic literature and industry reports the different roles have names and definitions that overlap and can cause confusion (Hoogervorst, 2017, p. 28). More on role distribution and other factors is explained in section 3.2.

Producer

The role of *Producer* is of vital importance in a DH system. Without thermal energy being produced, there is nothing to be distributed, delivered and consumed and therefore a DH system has no function. In fact, the producer is considered the first role in the value chain of DH, whereas the consumer is the last. The producer generates heat and feeds this heat into the district heating grid to be transported to a consumer with a certain heat demand (Tieben & Van Benthem, 2018, pp. 5-6). The role of producer can be fulfilled by a wide variety of different stakeholders.

Producers can be parties that generate heat either as a core business; the *'regular' producers*, as a by-product; the so-called *auto-producers* (Danish Energy Agency, 2017, p. 4) (Persson, 2015, p. ix) or as parties that both consume heat from and produce heat for the DH system; the so-called *prosumers*. Regular producers intend to produce heat, either directly or in combination with e.g. electricity production in a combined heat and power (CHP) plant. Auto-producers usually are companies that produce heat to be used in industrial processes or parties that extract heat from their processes in order to cool the process down. They have a surplus of heat that they can feed into the DH grid. Examples are steel factories that generate heat in their production process, data centres that need to cool their servers, supermarkets with excess heat from the cooling process in their refrigerators or sewage treatment plants that release heat in purification of the water. Prosumers are mostly households or (small) businesses that for example produce heat during the summer, through solar-thermal installations or cooling of their building, and consume heat during the winter for heating up their living or working areas or installations.

A producer can operate only one heat production facility, or several at the same time. The producer can also feed into different DH grids. Producers can be public or private organisations and can be very large in terms of heat generating capacity, or very small. Producers all produce heat, however the source they use to produce this heat with or extract the heat from can vary greatly in terms of size, temperature level, sustainability, intermittency and cost structure. Some sources are very dependent on geography, others are more flexible in selecting a physical location. For example, the technical and economic feasibility of exploiting a geothermal energy source are very dependent on location, whereas a heat-only boiler on natural gas is much more flexible in selecting a site.

Concluding; producers can greatly differ in terms of ownership, core business, production capacity and their heat sources can vary on temperature level, cost structure, sustainability and other characteristics. However, any party that produces heat and feeds this into a DH system fulfils the role of a producer within that system.

TSO

The *Transmission System Operator*, also called Transportation System Operator, (TSO) is responsible for the heat transmission system, which transports heat over relatively long distances, mainly from the heat sources (producers) to the distribution networks (DSO's), where heat is transferred in sub-stations (Hoogervorst, 2017, p. 8). The water that is cooled down is transferred back to the heat source. Sometimes large (industrial) consumers are also directly connected to the transmission grid (Tieben & Van Benthem, 2018, pp. 5-6). The transmission grid, like the distribution grid, can be considered a non-contestable natural monopoly (Wissner, 2014, p. 66) (Söderholm & Wårell, 2011, p. 744). Therefore, there normally is only one party that fulfils the role of TSO in a given area and thus has a local monopoly.

In some cases a transmission grid only connects one producer to a nearby distribution grid via a single pipe. In this case, the roles of TSO and DSO are probably integrated in one party. In other cases large-scale DH systems have a separate (monopoly) TSO and several DSO's (Gronheit & Mortensen, 2016, p. 67). There are also examples, like the Greater Copenhagen DH system, of multiple TSO's being active in one DH system, consisting of many interconnected distribution grids. Each of the TSO's covers its own area, due to the natural monopoly characteristic of transmission and distribution, but is connected to the other TSO's and also connects several DSO's that all have a monopoly in their own distribution grid (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, pp. 16-17).

Examples of DH systems with separate/unbundled and especially with multiple TSO's are scarce, as often the role of TSO is combined with the role of DSO, or there is no transmission at all, as is regularly the case in smaller, local DH systems with a single heat source within the distribution area (Tieben & Van Benthem, 2018, p. 11). In general the role of TSO is only necessary in a situation with a heat source that is remote from the distribution area or a situation with multiple distribution grids that are connected. In the first case, the roles of TSO and DSO are often combined by one stakeholder. Mainly in the latter case the TSO could be unbundled from other roles and be covered by a separate party. There are studies on the possibility of combining the roles of TSO and DSO, but unbundled from production and delivery of heat (Tieben & Van Benthem, 2018). This would then be comparable to the market order in the electricity and natural gas sectors in some countries, like in the Netherlands.

DSO

A *Distribution System Operator*, or DSO, is the responsible party for the heat distribution grid in a certain area. The distribution grid tends to be a more close-knit, dense network compared to the transmission grid. Distribution grids transfer the heat from the transmission grid, through a sub-station where heat is exchanged between the two grids, to a consumer or end-user (Hoogervorst, 2017, p. 8). The cooled water is transferred back to the transmission grid via the sub-station to be heated up by the producer(s) (Hoogervorst, 2017, p. 25).

The DSO is responsible for connecting small and medium sized consumers to the distribution grid (Tieben & Van Benthem, 2018, pp. 5-6). This can be done in two ways; directly or indirectly. The most common way is to indirectly connect the distribution grid to the building's internal heat circuit via a small heat exchanger. The building can for example consist of only a single dwelling or it can be a larger building with multiple apartments (Mazhar, Liu, & Shukla, 2018, p. 429). This 'front-door' sub-station containing a heat exchanger will simply be called "heat exchanger", to be able to distinguish it from the "sub-station" between the transmission and distribution grids. The other, less commonly used way is a direct connection (mainly in former Soviet-Union states), where the distribution grid and the building's heat circuit are directly connected and the hot water in the distribution grid flows straight into the building's heat delivery system. The advantage of this is found in avoiding heat losses that arise in the heat exchanger. Disadvantages are higher risks of damage, clogging, contamination and leakages (Mazhar, Liu, & Shukla, 2018, p. 429).

Like the transmission grids the distribution networks have clear natural monopoly characteristics (Söderholm & Wårell, 2011, p. 744). Therefore, DSO's normally have a local monopoly within the area of their grid. As is discussed above (under *TSO*) there are examples of DH networks with multiple DSO's, but these all have a monopoly on distributing heat within their network area (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 16). In several cases they do however compete with other heating technologies, like natural gas networks. It is remarkable that there are no (known) examples of distribution grids on which more than one provider of heat is active. This is also the case in the Greater Copenhagen system, where the roles of provider and DSO are integrated and consumers cannot choose their own heat provider (2016, p. 18). It seems that the role of *DSO* and the role of *Provider*, which is discussed below, are very often – if not always – combined in one stakeholder that fulfils both roles, probably due to the incentive an integrated DSO has to not grant access to other parties (Tieben & Van Benthem, 2018, pp. 16-17). Examples of DH systems where one DSO and one provider are active, both unbundled from each other, are also hard to find. Unlike the electricity and/or gas sectors in some countries, where several providers are active on the same distribution grid, DH grids are often considered too small and locally oriented to accommodate multiple providers.

However, opening up the provider-side of the DH system to multiple producers is sometimes discussed, with mixed conclusions (Tieben & Van Benthem, 2018) (Hoogervorst, 2017). Still, there are new developments of DH systems where these roles will be separated, mainly in the Netherlands. In several towns and cities DH systems are developed in which the roles of producer, DSO and provider are fully unbundled and in some cases even multiple producers and providers could be active alongside each other (Firan, 2020) (Enpuls, 2020). This organisational design of DH systems is not common, but might appear more often in the future.

Heat load planner

The *heat load planner* is, unlike the TSO and DSO, not responsible for physical DH infrastructure or other tangible assets. This role is entirely focused on planning of the dispatch of heat production and the balancing of supply and demand, to guarantee sufficient heat production to match heat demand at all times. The description of this role is somewhat experimental, as it seems existing literature does not really distinguish this role within DH systems. In this research the identification and description of this role is mainly based on the existence of a stakeholder in the integrated Greater Copenhagen DH system that fulfils only this role: *Varmelast*. This organisation serves as a model for the description of the role of heat load planner.

In case of one integrated DH company that covers the whole DH value chain – from production to delivery – the role of heat load planner, covering dispatch of heat load and balancing of supply and demand, is fulfilled by that same company. However, when the roles of producers and TSO/DSO are (partially) unbundled and performed by different organisations, like in Greater Copenhagen, the role of heat load planner is better visible and more important. In that case it is less obvious which of the parties should be responsible for balancing supply and demand and (economically) optimising heat production. As the task of balancing production and consumption in the physical grid – which is the responsibility of the TSO and/or DSO – is closely related to the theoretical matching and economic optimisation of supply and demand, it seems logical that the role of heat load planner is performed by the same organisation that fulfils the TSO and/or DSO role.

In their report Tieben & Van Benthem discuss the role of the *shipper* or *"programme responsible party"* as the party that is responsible for matching supply and demand in by contracting sufficient production capacity to match contracted demand by its consumers. Another role – the "system services authority" – ensures the balance within the heating grid and, if necessary, coordinates the availability of reserve capacity (Tieben & Van Benthem, 2018, p. 6). These two roles are not entirely accurate in representing the role of heat load planner as intended in this study, but show some characteristics. When looking at the responsibilities of Varmelast in the Greater Copenhagen system, it seems these are mainly in the area of what is described as activities of the *shipper* – matching supply and demand – although not entirely and in a significantly different way. Varmelast is responsible for calculating the most cost-efficient way to produce sufficient heat at any given time, on an hourly basis, considering the technical limitations of the grid and the plants (Varmelast, 2020). Based on the offers producers make, Varmelast presents a 'heat load plan' that establishes which production facilities supply what amount of heat for the offered price (Varmelast, 2020).

Concluding; the role of heat load planner is responsible for balancing heat production with heat consumption by ensuring the right amount of heat is procured to match the forecasted heat consumption at any time. The heat load planner can also optimise the heat load based on the targets that are set, like to aim for the lowest consumer heat price by optimisation based on lowest operational costs.

Provider

Like in the electricity sector in many countries the role of *Provider* can also be identified in DH systems. According to Tieben & Van Benthem the main responsibility of the provider is to contract consumers of district heating, agreeing on a DH price – often with both a fixed and variable component – and a maximum capacity of the connection (Tieben & Van Benthem, 2018, p. 6). The provider is also responsible for contracting sufficient heat production from producers in order to cover the aggregate demand of all of its consumers. Furthermore, the provider often performs energy metering and billing of its consumers.

Even though there could in theory be more than one heat provider in a DH system, there are no examples of competition between different providers within the same DH system (Gronheit & Mortensen, 2016). In most cases the role of provider is fulfilled by the same stakeholder that performs the role of DSO and thus owns and operates the distribution system. This is the case in many European countries, like Denmark, the Netherlands (Hoogervorst, 2017, p. 10) and Sweden. Because the provider almost always owns the distribution grid too, it has the possibility to repel potential new entrants to the provider-market, thus maintaining its local monopoly and preventing competition (Hoogervorst, 2017, pp. 10-11). This leads to the fact that in the vast majority of the DH systems the roles of provider and DSO are integrated into one stakeholder and in many cases this party is also the only heat producer within the system, resulting in a vertically integrated DH company that has a monopoly on all three roles it fulfils, namely the roles of producer, DSO and provider. In these cases technically every role is fulfilled by the same party, as the roles of TSO (if relevant) and heat load planner are – logically – also integrated in that same party.

Consumer

The role that is probably most relatable to many people is that of the *Consumer*. However, consumers appear in different sizes and types. The most important consumer categories are residential buildings and industrial facilities, although there can be significant differences per country, as is shown in Figure 51 in Appendix A. In a country like China, the majority of DH is deployed for industrial use, where the residential sector forms the largest consumer group in Russia and the European Union (Werner, 2017, pp. 619-620). Other countries not only have a much smaller DH sector, they might also see different representation of the various consumer groups, like the fact that DH for residential heating is almost non-existent in the United States.

What all consumers have in common is the fact they 'consume' heat, as they receive thermal energy through a heat exchanger near or within their building. However, many aspects of heat delivery to and consumption by these end-users can differ. For example: the required capacity of the connection to the DH system, in terms of kW or MJ/h, the supply temperature at the 'doorstep' of the consumer, which could vary from 30°C to 100°C or more, or the demand 'pattern' of the consumer throughout the year (Hoogervorst, 2017, p. 8). For residential and commercial consumers the forward temperature and the connection capacity mainly depend on the degree of insulation, the quality of the heat delivery system within the building and on the total volume of that needs to be heated. For industrial consumers these elements are more dependent on that company's production process and the 'destination' of the received heat; for example for reaching a comfortable temperature for workers on a factory floor or for heating a greenhouse to grow tomatoes.

A last aspect of consumers is the fact they can have greatly varying preferences. Many consumers consider the price they pay for DH as the most important assessment criterion, particularly compared to alternative heating technologies (Janssen, 2015, pp. 40, 45-47). For some consumers, both residential and organisational, the sustainability performance of their heating is vital, where others simply do not mind besides receiving an adequate service (Hoogervorst, 2017, pp. 10-11). For commercial and industrial consumers these same differences occur, although preferences do not depend on personal wishes, but on organisational goals and targets.

District heating value chain

After discussing the above six roles, Figure 3 below briefly summarizes this. The figure shows the roles in order of 'appearance' within the DH value chain, from left to right. It also illustrates which (tangible) assets these roles are

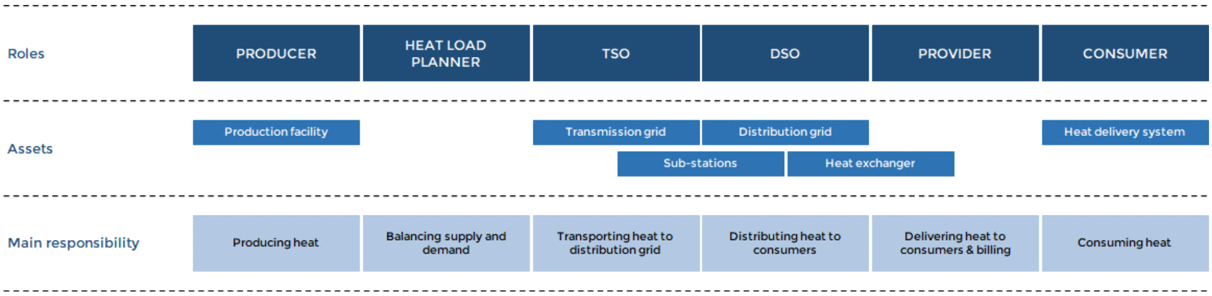


Figure 3 – The 'value chain' for DH systems; production to consumption. Per role, assets and main responsibilities are shown

responsible for – in two cases assets could be accommodated by two roles. Lastly, the figure shows the main responsibility or activity of each of these six roles. Not all of these roles are always clearly 'visible' within a DH system, but they are always all six fulfilled within every system. However, they are often hard to distinguish, because roles like heat load planner, TSO, DSO and provider are regularly integrated within one stakeholder.

Other roles

Besides these six main roles, all active within the value chain of the DH system, there are some other roles that are relevant to the functioning and operation of the DH system. These roles will just be mentioned very briefly, only one role will be discussed a bit more elaborate; the role of *Government*.

In contrast to the six main roles within the value chain, there also are roles that are less visible or are not directly needed for the system to operate, but can be considered important. Examples of these roles are (energy) *service providers* like energy service companies (ESCO's) that perform all kinds of tasks for other stakeholders in the system, *consultants* that provide legal assistance, financial advice or engineering services, or *supervisors* like supervisory authorities that enforce rules and regulations that are set by law, as for example the Autoriteit Consument & Markt in the Netherlands (Autoriteit Consument & Markt, 2020) or Forsyningstilsynet in Denmark (Forsyningstilsynet, 2020).

As introduced above, the most important 'additional' role is the role of *Government*. This role exists on different levels, more specifically on the national, regional and local level. Examples of stakeholders that fulfil this role are national governments, often consisting of all kinds of departments and agencies, municipal governments that control cities and towns and different kinds of regional governments, like provinces, counties, metropolitan areas or regional water boards. The responsibilities and activities of governments mainly depend on their 'level', within a country's constitutional and organisational structure. In many north-western European countries the national government is the (main) legislator and 'lower' governments, like municipalities, act on a more operational level. Regarding DH, national governments are normally the stakeholders responsible for legislation and regulation, where supervisory authorities (often being part of the national government) enforce these rules. Both national and municipal governments can be policy-makers and financers (e.g. via subsidies), although again on different levels. Execution and implementation is often the responsibility of regional and local governments. More specifically: in many countries provinces and especially municipalities are responsible for regional and local heat planning, thus directly influencing the development of (new) DH systems (Danish Energy Agency, 2017, pp. 11-12, 16) (Programma Aardgasvrije Wijken, 2020).

3.2. Factors in district heating system functioning

District heating systems generally are large, complex systems with high numbers of stakeholders and many interfaces with other systems. Therefore, identifying and describing different factors – elements that influence these complex systems and their functioning (Oxford University Press, 2020) – can contribute to better understanding of the way they could be designed to serve the needs and requirements of their stakeholders. This section introduces fifteen factors in four categories; *technical and physical factors*, *regulatory and policy factors*, *economic factors* and *societal factors*.

3.2.1. Technical and physical factors

Some important physical or technical factors influence the design of DH systems. These factors may relate to the physical dimensions of the system, to technological elements like connection to the end-user's system or coupling to other energy systems and to factors like the temperature of the transport medium that flows through the DH grid.

System size

The size of a DH system also influences the way it is or should be operated or regulated. For example, the size of a DH system strongly affects the cost structure and is therefore a relevant factor in determining whether or not third-party access is to be introduced (Pöyry Management Consulting Oy, 2018, p. 32). There are various physical dimensions that can be relevant, here the focus is on the system's size. In turn size is divided over three factors, also mentioned by Magnusson (2012, p. 452); the *supply area*, which is represented by the geographical area (e.g. in km^2) the DH system covers, the *number of connections*, which is represented by the actual number of buildings that is connected to the network and the (total) *energy supplied*, represented by the thermal energy that is delivered per annum to all end-users within the DH system.

Supply area

A DH system supplies buildings only in a limited area, it is not a nation-wide infrastructure like electricity networks often are. A DH system can cover a small village, a neighbourhood of a larger town or even an entire city. Gronheit & Mortensen explain that larger DH systems, covering a whole town or urban area, show more potential for competition on heat production (2016, p. 65). Although they refer to an area when discussing the size of the system, the area that is covered might be a less relevant factor than the amount of energy supplied by the system.

The size of the supply area can however influence other factors. The supply area is mostly relevant in relation to the other two size-factors, which are discussed below. Together with either the number of connections or the total energy supplied, the area influences the density of the DH system. In combination with these factors, it constitutes either the heat demand density or the connection density. In turn, these densities respectively affect the average variable costs (AVC) through heat losses in the distribution of energy (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 22), or the average fixed costs (AFC) that a connected consumer pays (Patronen, Kaura, & Torvestad, 2017, p. 77). The latter can be because of economies of scale in constructing and operating the DH grid, thus lowering the average costs per km of pipe, as the distribution constitutes a natural monopoly, or because of the higher number of connected consumers per km of pipe. The heat demand density (HDD) seems to rise with the size of the DH system, as shown by Söderholm & Wårell (2011, p. 747).

The size of the DH system area thus mainly influences the DH system design in combination with other factors. However, size possibly also directly influences some aspects. For example, it can be imagined that citizens in small towns feel more connected to their community and therefore show more willingness to participate in a local DH system, as they feel more responsible or have the feeling they have more influence. The Danish district heating sector indicates this could be true, as 83% of the almost 400 DH companies was owned by cooperatives, but these were responsible for only 34% of the national heat supply through DH. In contrast, only 12% of the DH companies were owned by municipalities, but 58% of the heat supply was covered by these (Rønne & Nielsen, 2019, p. 226). Hence cooperatively owned DH systems are often smaller sized than municipally owned systems. This suggests there is a relation between citizen participation, in the form of cooperatives, and the size of the DH system. This relation could therefore be further studied and taken into account in the planning process.

Number of connections

Before discussing the influence this has on the DH system, it is necessary to first define a 'connection'. Naturally, not all connected buildings to a DH system are the same. A connected single-family home normally differs significantly from an apartment building in terms of heat demand, but in both cases only one building is connected. A single-family home on average only has the heat demand of one household, where another connected building accommodates fifty apartments and therefore has a heat demand that is multiple times higher. Obviously this has consequences for the heat demand density, although the connection density theoretically stays the same. To prevent confusion around the term 'connection', it is sometimes considered easier when this refers to the number of households that receive heat from the DH network (Segers, Van den Oever, Niessink, & Menkveld, 2019, p. 16).

Options for establishing the connection fee could be based on a fixed fee for all consumers with a connection under a certain maximum size in kW, like in the Netherlands (Autoriteit Consument & Markt, 2018) and Germany (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 79) or as in Denmark based on the size of the living area of the consumer's house or apartment (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 33). The fixed connection fee will in most cases also be much higher for an apartment building as a whole than for a detached single-family house, more or less proportional to the number of apartments. The fee could then for example be divided equally over the apartments. However, as in this situation the investment costs for infrastructure do not rise proportionally to the increase in connections, the AFC will probably decrease when more apartment buildings are connected compared to the number of detached houses. This is because the connection density, represented by the number of connected buildings per km^1 of pipe or per km^2 of DH area, as explained under *Supply area* and *Heat demand density*, does rise and thus decreases the AFC. This can be translated into lower costs for end-users, or higher profits for DH companies (Blom, Rozema, & Van der Veen, 2019, p. 31), depending on local market structure and regulation.

In case of a commercial building or industrial facility, it is hard to talk about a certain number of connected households, although the heat demand is multiple times that of a single house. This illustrates that the number of physical connections does not always tell the whole story about a DH system. In case the network only connects residential buildings this is often easier to understand, more representative and more relevant for the system. When a DH system also connects significant numbers of non-residential buildings, it could be wise to differentiate between residential and non-residential connections. For the different types of connections various fees can be applicable, depending on the size of the connection that is needed to facilitate the heat demand of the consumer in question.

Another way to explain the size of a system is to present the number of connections in terms of 'household equivalents' or HEQ. This expression refers to the average yearly demand of a 'normal' household in terms of GJ per year. This way, the size of the system can be more relatable to some people, as it refers to a certain number of households. For example, with an average yearly household consumption of 30 GJ per year, a DH system that supplied 180 TJ/year or 0.18 PJ/year would be equal to 6,000 household equivalents, or 6,000 HEQ. If the system only covers a residential area, the actual number of buildings and especially the actual number of households might be close to the number of HEQ. In case there are significant numbers of non-residential buildings connected, the number of HEQ could be quite different from the actual number of buildings, as industrial facilities often have very high heat demands. Furthermore the average household heat demand, which constitutes the HEQ, can differ between various areas and authors, making it harder to compare DH systems (Segers, Van den Oever, Niessink, & Menkveld, 2019, p. 16).

Concluding, the number of connections is mainly relevant when combined with the DH supply area to compose the connection density. It can say something about the size of the heat market, although there are large differences in heat demand between connected buildings. By expressing the number of connections in terms of HEQ diverse systems can be compared. However, this comparison is not entirely accurate, as average household heat demand can vary significantly between countries and is does not incorporate differences in building stock (residential, commercial, industrial) between areas.

Energy supplied

The total amount of energy supplied to end-users in the DH system strongly influences the potential for competition in the market. More than the number of connections and especially more than the size of the DH supply area, it shows the size of the market for heat producers and providers that are active in the system. While there is broad consensus on distribution being a natural monopoly, it is often debated if the production of heat for

DH can be considered a natural monopoly. Production is often considered to constitute a natural monopoly in small DH systems (Government of Sweden, 2011, p. 21). Söderholm & Wårell explain the market size is very relevant in relation to the size of the production facilities in that market. Combined with the natural monopoly of the distribution and the (exclusive) access the DH company has to the network, the DH system as a whole, thus including production, can be viewed as a natural monopoly in case the market is small enough and the production facilities are of considerable size (Söderholm & Wårell, 2011, p. 744). This relates to the relative size of the DH market in comparison with the incumbent heat production facilities. Tieben & Van Benthem also base their argumentation on this, as they state the heat demand per DH system is relatively small compared to the efficient size of a production facility, hence the fact that many systems are supplied by only one plant. In practice, this results in local monopolies (Tieben & Van Benthem, 2018, p. 15). Concluding, the heat market size strongly influences the potential for competition amongst producers in the DH system (Söderholm & Wårell, 2011, pp. 748-749).

The size of the DH system in terms of energy supplied per year also seems to be correlated with the heat density of the network, as is shown by Söderholm & Wårell for around 200 DH systems in Sweden (2011, p. 747). The heat (demand) density, in GWh per km, more than doubled for systems that supplied over 500 GWh/1.8 PJ per year, compared to systems that supplied under 100 GWh/0.36 PJ pear year. This does not show a causal relationship, but does indicate a correlation between the size of the heat market and the heat demand density of DH systems in Sweden, which is likely to hold for other countries as well.

Where the total amount of heat that is supplied per year is normally used to define the size of the system, it does not automatically express the physical size of the system in terms of kilometers of pipe or number of connected buildings. As explained under *Number of connections*, sometimes the term 'household equivalents' or HEQ is used to represent the number of connections to the system. In a way, this expression strongly refers to the heat supply by the system, as it represents the total thermal energy supply divided by a value that represent the average household demand, the HEQ. For example, a DH system of the size of 6,000 HEQ represents a yearly supply of 180 TJ, given an average yearly household demand of 30 GJ.

However, this way of expressing total energy supply makes it harder to compare DH systems across countries, as the average yearly household consumption may vary significantly between colder and warmer areas. The unit of HEQ is therefore considered not optimal for expressing the system size in terms of total energy demand. It can be useful in comparing different systems in terms of connections, although this also has its disadvantages, as explained under *Number of connections*.

Concluding; the DH system size can be expressed in different ways, that all need to be provided with some additional context. The method that is easiest to read and to compare across countries is simply stating the total energy supply in the system in terms of TJ or PJ per year. This is the most 'pure' way of expressing, as a GJ is the same in all DH areas. Still, some context is needed to understand other characteristics of the system. What share of this heat supply covers residential areas and which part is dedicated to industrial or commercial buildings. Furthermore, combining this information with the physical area the DH system covers can provide insight on the heat demand density and the connection density of the system. These are valuable in assessing the business case of a system. More on this below.

Heat demand density

The aspect of density is important to DH (Lund, et al., 2014, p. 3). There is broad consensus on the relevance of heat demand density (HDD) to the economic viability of DH systems. Heat demand density can be expressed and quantified in several ways. Some authors focus on linear HDD, which is the amount of thermal energy delivered per kilometre of DH pipe, to be expressed in MWh/km^1 (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 132), others focus on the heat demand of connected consumers in a specific area, expressed in MWh/km^2 or TJ/km^2 (Möller, Wiechers, Persson, Grundahl, & Connolly, 2018). HDD, either linear or area density, is strongly correlated with urban/building density or population density. This follows from the fact that heat demand per capita is relatively comparable in cities with low and with high population density, as shown in Figure 1, and therefore HDD grows with rising population density (IRENA, 2016, p. 37).

Several authors point out that a higher heat demand density benefits DH by lowering the average costs. Möller et al. show that the average investment cost or AFC increase exponentially with decreasing HDD, as is shown in Figure 4. Some researchers state that for a DH system to be economically viable or even sensible in general, a certain minimum heat demand density is required (Möller, Wiechers, Persson, Grundahl, & Connolly, 2018, p. 287) (IRENA, 2016, p. 19), although the actual value that they take for this minimum can differ. The average costs for DH are usually lower in densely populated areas (Patronen, Kaura, & Torvestad, 2017, p. 77) and/or with a high building density (Mazhar, Liu,

& Shukla, 2018, p. 431). Besides population density and the (average) heat demand per capita, there is another factor that influences the heat demand density, as is shown by Wissner (2014, p. 65). He states, following (the updated version of the 2003 paper by) Gronheit & Mortensen (2016), that DH distribution networks require a certain degree of connection density. He suggests the need for a certain connection density is the reason for the support obligatory connection to DH receives in some areas. Higher connection density reduces costs per connection. Depending on the price structure the system owner applies, eventually this either reduces the AFC for the consumer or increases the profit margin of the grid operator. The latter also depends on the price regulation that is in place (see section 3.2.2), the first depends on the policy regarding distribution of DH costs that is in place (e.g. socialisation, see section 3.2.3).

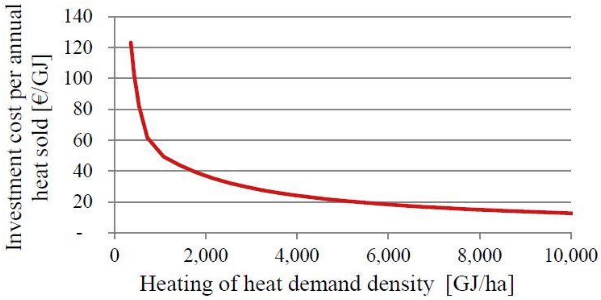


Figure 4 – Correlation between HDD and investment cost per GJ (Möller, Wiechers, Persson, Grundahl, & Connolly, 2018)

Although a high HDD is a factor that is beneficial to DH, it is not necessarily so that increasing the HDD is the right thing to do. Several factors influence the heat demand density, but increasing population density, the average household size or the heat demand per capita are probably not the most intelligent, nor realistic ways to increase HDD and boost the viability for DH. Lowering the level of insulation of buildings or increasing the average building volume are also not the most practical, economically efficient or smart ways to boost DH. However it is sensible to consider DH mainly for areas that already have a certain population density and therefore a certain HDD. Secondly, it is important to realise the pre-defined (minimum) connection density that is needed for a viable business case. The latter appears to be the 'easiest' approach to increase the HDD, though it is the HDD of the DH system, not of the area. The way connection density is stimulated needs to be carefully considered. One method is discussed under *Obligatory connection* in section 3.2.2.

Temperature regime

The temperature of the medium – generally water, sometimes steam – in a DH system is an important factor in the functioning of current DH systems (Werner, 2017, p. 622). The temperature regime of a DH system is not established by a 'forward temperature' only, the 'return' temperature is also important. The forward temperature – also called supply temperature – is the temperature level of the heat supply pipe, the return temperature is the level of the water that is cooled down and transported back to the production facility. Existing DH systems operate on widely varying temperatures, but roughly with a forward temperature that lies between 20°C and 120°C; in Denmark, for example, the majority of DH systems has a forward temperature that is above 80°C, with return temperatures around 40°C-45°C (Danish Energy Agency, 2017, pp. 20-21).

The terminology that is used to refer to DH systems with a certain temperature regime seems to vary significantly, not only per country, but also per organisation or profession (Hoogervorst, 2017, p. 16). Some authors talk about 3rd-, 4th-, and 5th-generation DH systems (C40 Cities, 2016) (Lund, et al., 2014) (Lund, et al., 2018) (Buffa, Cozzini, D'Antoni, Baratieri, & Fedrizzi, 2019), others refer to low-, medium- or high-temperature systems and many of them (Persson, 2015) (Hoogervorst, 2017) (Danish Energy Agency, 2017). Most important is to realise there are different temperature levels on which a system can operate and to understand the ways that temperature regime can affect the system's functioning.

There are a few important ways a system's temperature regime can influence its operations. One of these ways is through the difference between forward and return temperatures, as many production facilities – whether these are combined heat and power (CHP) plants, heat pumps or solar thermal installations – operate more efficiently when the difference between the temperature of their input (the return temperature) and their output (the forward temperature) is maximised (IRENA, 2017, p. 24). This is also the reason it is important to properly 'cool' the DH system in the buildings of its consumers, as this both maximises the energy that is delivered per m^3 of water and minimises the heat losses in returning that water to the heat source (Danish Energy Agency, 2017, pp. 20-21). A second way the temperature regime can influence the DH system's operation is because it determines how much heat is lost in transmission and distribution; lower temperature regimes – mainly forward, but also return temperatures – reduce heat losses in the DH grids (Danish Energy Agency, 2017, pp. 20-21) (Hoogervorst, 2017, p. 26) (Schmidt, et al., 2017, p. 28). Another way the temperature regime affects system functioning is because of the 'accessibility' of the system for low-temperature heat sources, which include many renewable heat sources (Danish Energy Agency, 2017, pp. 20-21) (Van Vliet, et al., 2016, pp. 1-2). Many of these effects of the temperature regime seem to result in a shift towards lower temperatures, which is a current trend in many countries. However, another effect that can function as a barrier to this trend is the fact that many buildings need a certain minimum forward temperature in order to be able to be sufficiently heated. This is mainly the case in older, poorly insulated buildings and buildings with an insufficient heat delivery system (Danish Energy Agency, 2017, pp. 20-21).

Type of heat source

Another technical or physical factor of DH systems regards the type of heat source that feeds into the system. This factor is probably also the most tangible and visible of all fifteen identified factors. When discussing the type of heat source, this not only considers the technology that is used, but also aspects like the fuel or 'source' of heat or the availability of the heat supply.

The heat source type is a very relevant factor in several ways. First, every heat source has a certain temperature level of its heat output, on which it operates most efficiently. This depends on the production process and on the actual heat 'source'. For example: a combined heat and power (CHP) plant produces heat via combustion of coal, biomass or natural gas and thus its production process reaches much higher temperatures than facilities that supply excess heat from supermarkets or datacentres, where the main heat 'generating' process encompasses extracting heat from refrigerators or server-rooms. The supply temperature level of the heat sources has to match the forward temperature level (as discussed above) of the DH grid in order to operate efficiently. Therefore, there is a strong relationship between the supply temperature of the heat source(s) and the temperature regime of a DH system INSERT SOURCE.

Furthermore, heat sources can be:

- Dependent on a physical location, like geothermal plants that depend on the geological characteristics of the location or solar-thermal facilities that depend on the number of sunshine hours (Tieben & Van Benthem, 2018, p. 15);
- Dependent on the availability of other facilities, like opportunities for excess heat supply depend on the presence of supermarkets, datacentres or industrial facilities, or like sewage water treatment plants;
- Technically free to place anywhere, like CHP-plants or waste incinerators, although these types are indeed depending on the availability of fuel supplies, ranging from imports of coal or natural gas to the collection of solid waste for incineration;

This categorisation of heat sources based on dependency on their location illustrates the fact that the heat source strongly influences the feasibility of a DH system, as the business case of a DH system depends partially on the availability of suitable heat sources (Hoogervorst, 2017, p. 27).

Heat sources can be assessed on criteria like their temperature level, their availability (e.g. seasonal or daily intermittency), their average total costs, their average CO_2e-emissions, their (efficient) size, their necessary investments and many more. Some (lower temperature) heat sources are depending on lowering of the temperature regime of a DH system, like might be the case for heat pumps, solar thermal facilities, some forms of excess heat supply and geothermal plants (Schmidt, et al., 2017, p. 28) (Danish Energy Agency, 2017, pp. 20-21). Several of these relatively new and more sustainable heat sources are also considered to fare better in a more 'open' DH market, where third-party producers have fewer responsibilities to (individually) guarantee heat supply on the mid and long term (Den Ouden, Hoeksema, & Graafland, 2015, p. 15). Important to realise is the fact that heat sources (and the producers that operate them) can – willingly or unintentionally – create a lock-in situation, wherein there is such a high dependency on a heat source that a coal-fired CHP-plant cannot be phased out (Het Financieele Dagblad, 2020) or even the security of supply may be jeopardised (Tieben & Van Benthem, 2018, p. 5). Reducing this dependency on one heat source and/or heat producer could not only stimulate security of supply, but also improve societal support and even boost investor confidence (Hoogervorst, 2017, p. 55).

Integration of energy systems

The last technical factor does not only regard the DH system itself, but also considers other energy systems. This factor covers the *integration of energy systems*, mainly with regard to the electricity system. Besides coupling of DH systems with the electricity grid, including storage capacity in the DH system is also considered within the description of this factor, even though it could be viewed as an integral part of the DH system itself.

The integration of other energy systems with DH has already been going on for decades, as many systems receive heat from CHP-plants that often produce electricity as their core business and supply heat for DH to increase energy efficiency (Gronheit & Mortensen, 2016, p. 64). In CHP-plants heat production always exists in relation to electricity production, where the ratio between power and heat production also has an influence on the production costs that are allocated to each of the end-user prices. This relationship even was the main reason for establishing a heat load planner in the large and integrated DH system of Greater Copenhagen, as was already briefly mentioned in section 3.1 (Varmelast, 2020). Besides the connection to the electricity sector via CHP-production, the rising share of intermittent renewable energy forms a new reason to work towards stronger integration of electricity and DH (Averfalk, Ingvarsson, Persson, Gong, & Werner, 2017, p. 1275).

There have been several studies that consider the possibilities for using variable power generation in heat production via (utility-scale) heat pumps and electric boilers, showing promising results. However, there also are barriers, for example in the fact that many DH systems operate on a relatively high (forward) temperature which will reduce the competitiveness of heat pumps as a result of lower efficiency (Averfalk, Ingvarsson, Persson, Gong, & Werner, 2017, p. 1276). In general higher shares of variable power generation – like wind power – would increase the benefits of integration of heat pumps and electric boilers (Lund & Persson, 2016, p. 130). The use of heat pumps for integration of the power system and a DH system would be dependent on the availability of local (base) heat sources, like industrial excess heat, wastewater treatment, supermarkets, datacentres or various surface water bodies (Lund & Persson, 2016, p. 131). Electric boilers can – like CHP-plants, as discussed on the previous page – be placed almost anywhere, at least on a technical level.

One of the main benefits of integration of power and DH systems and the introducing of thermal energy storage facilities is the possibility of "peak-shaving", both of power generation and heat production (Li & Wang, 2014) (2017, pp. 283-285). Heat production with heat pumps or electric boilers when power generation peaks could reduce the difference between electricity supply and demand. Thermal energy storage – especially in case of seasonal storage – could 'shave off' peaks in heat production and better utilise heat that is produced during times with relatively low heat demand, like in summer. Four main concepts of seasonal thermal energy storage can be distinguished: tank thermal energy storage (TTES), pit thermal energy storage (PTES), borehole thermal energy storage (BTES) and aquifer thermal energy storage (ATES) (Sørensen & Schmidt, 2018, p. 2). An schematical representation is provided in Appendix B. Especially the integration of (seasonal) thermal energy storage could be key in optimising the efficiency of DH systems and better integrate power and district heating systems.

3.2.2. Regulatory and policy factors

District heating systems are significantly influenced by regulation and public policy. Wissner (2014) states that the DH sector needs to be regulated in principle, although few European countries seem to have direct regulation of DH systems in place and only some retail price regulation regimes exist. He distinguishes several forms of regulation, roughly divided in regulation of the DH distribution grid (both access to the grid and pricing of the grid) and regulation of the entire DH system (end-user price). Other factors of regulation or policy are discussed by different authors, e.g. unbundling of distribution and/or transmission grids (Magnusson, 2013) (Tieben & Van Benthem, 2018) (Hoogervorst, 2017), obligatory connection (Wissner, 2014) (Sandberg, Sneum, & Trømborg, 2018) and forms of regional or national planning by governments (Magnusson, 2013) (Magnusson, 2012) (Sandberg, Sneum, & Trømborg, 2018). These regulatory factors will be discussed below.

Third-party access

A widely debated topic is the possibility for *third-party access* (TPA) in DH systems. TPA is theoretically possible in both the wholesale market/producer-side and the retail market/provider-side of DH. In several European countries a debate on TPA in electricity and gas markets has been going on around the time many of these markets were liberalised. Due to the natural monopoly that characterises the electricity grid, third parties have to be granted access to the network in order to ensure effective competition after liberalisation (Söderholm & Wårell, 2011, p. 742).

As there often is a clear incentive for vertically integrated DH companies to not grant third parties access to the network, regulation might be necessary to stimulate competition in the network (Söderholm & Wårell, 2011, pp. 744-745). Wissner states DH distribution grids are non-contestable natural monopolies, as there are barriers to free market entry and exit, and therefore should be regulated. Denial or reduction of access is considered abuse if it cannot be objectively justified, e.g. because of functionality, safety or capacity issues (Wissner, 2014, pp. 65-66). Different forms of TPA can be distinguished (Tieben & Van Benthem, 2018, p. 22) (Söderholm & Wårell, 2011, p. 743):

- *Voluntarily negotiated TPA*; in this case the DH network owner can negotiate with potential third parties that request access to the network, but the owner is also free to not negotiate and can therefore easily deny access to the applicant

- *Obligatory negotiated TPA*; where the DH network owner is obliged to enter into negotiation with a third party that asks to be admitted to the network. Access conditions are determined during or after negotiations (ex-post) and no provisions have been set on beforehand. There commonly is a possibility for arbitration in case negotiations do not succeed
- *Regulated TPA*; meaning the network owner is legally obliged to provide access to third parties based on predefined conditions and fees. These are defined ex-ante by a supervisory authority. In case the party requesting access to the network meets the predefined criteria the network owner automatically needs to allow this access.

It can be questioned what the difference is between voluntarily negotiated TPA, as described by Tieben & Van Benthem (2018) and no regulation regarding TPA, as in both cases the DH network owner is free to either grant or deny access to a requesting party. Furthermore, experiences from Sweden have shown that obligatory negotiation regarding TPA to DH networks has not reached the intended effect. In 2011 a special investigation concluded that therefore regulated TPA should be introduced in all networks (Government of Sweden, 2011, p. 22). Wissner also states a (sector-) specific regulation could be preferred over individual decisions by a supervisory authority or court, as the latter might be more costly when access is requested regularly (2014, p. 66).

TPA to the DH grids should always be non-discriminatory, meaning parties cannot be excluded on a random or arbitrary basis, but only on the ground of not meeting access criteria. Refusing access to one party where another (comparable) party has been granted access to the same market would be considered discrimination. Dominant parties, e.g. a monopolist like the network owner, are acting abusively when treating comparable customers in a discriminatory manner without objective justification (Kotlowski, 2007, p. 104). According to Pollitt non-discriminatory access is essential for the extension and deepening of competition (2008, p. 704).

Several authors suggest regulated TPA should be combined with unbundling of distribution from the other activities in the DH system. The earlier mentioned Swedish investigation suggests a legal separation of production, distribution and ‘trading’ is necessary in case a situation of competition arises from the introduction of TPA, although exceptions can be made by a supervisory authority (Government of Sweden, 2011, p. 22). Söderholm & Wårell even state that regulated TPA requires a vertical separation/unbundling of the distribution network from production activities. This separation should ensure non-discriminatory access to the network, so (in theory) price regulation only needs to address the grid operation, although in practice the competition in heat production may be limited (Söderholm & Wårell, 2011, p. 744). Hoogervorst mentions the necessity of legal unbundling of distribution grids in case competition between retailers/providers of heat is wanted. However, this (legal) unbundling could also, for example, hamper the cascading of heat delivery in the network and therefore the desirability of unbundling needs to be carefully studied and considerated (Hoogervorst, 2017, pp. 11, 51). Unbundling will be further discussed below.

Concluding, access to DH systems is, at least in theory, possible for both producers and providers/retailers, it should be non-discriminatory and it can be stimulated in different ways, but regulated TPA is considered to be most effective.

Unbundling

Over the last two decades many European countries have introduced regulation regarding the *unbundling* of transmission networks in their electricity systems and, to a lesser extent, in their natural gas systems. These regulatory developments followed concerns about the realisation of non-discriminatory access to the networks and the stimulation of sufficient and efficient investments in new (production) capacity (Pollitt, 2008, p. 704). More recently a similar debate arose in the DH sector of the Netherlands. Like in other European countries, there have been discussions on the stimulation of competition in DH systems and the necessity of access to and/or unbundling of DH networks (Wiebes, Kamerbrief Warmtewet 2.0, 2019) (Tieben & Van Benthem, 2018) (Hoogervorst, 2017).

Unbundling can be implemented in different ways. There are four different levels of unbundling that can be distinguished (Tieben & Van Benthem, 2018, pp. 6-7) (Künneke & Fens, 2007, p. 1922):

- *Administrative unbundling*; network operation and exploitation remain part of the same company as production and sales/delivery, but financial accounts of the network activities are separated from the rest, according to the principle of "Chinese walls".
- *Organisational unbundling*; the network activities are accommodated in a different organisational unit within the same company. Organisational unbundling is often in addition/essential to administrative unbundling. Staff is assigned different business divisions that function independently, but are all controlled by the central management of the company.

- *Legal unbundling*; in this form the network activities are accommodated in a separate legal entity, apart from the production/providing of energy. Ownership of the different legal entities may still be with the same holding company.
- *Ownership unbundling*; the most severe form of unbundling requires separate ownership of network activities. In addition to accommodating network activities and other operations in different legal entities, the shares and thus control of these entities may not be held by the same holding company.

Tieben & Van Benthem describe unbundling as a measure that could be taken to let the DH sector function more efficiently, although this can be aimed at different goals (e.g. efficient pricing based on marginal costs or efficient production considering possible economies of scale). Evaluating the effectiveness of unbundling should therefore take into account the political priorities regarding the public goals of affordability, reliability and sustainability of the heat provision (Tieben & Van Benthem, 2018).

As explained under *Third-party access* TPA is possible in both the production-side/wholesale market of DH and in the provider-side/retail market. Hoogervorst claims competition between retailers in the DH market is only possible when (legal) unbundling is introduced, although there could be disadvantages in the field of technical optimisation, e.g. cascading of heat through fine-tuning of the physical design to the different supply contracts and suppliers (2017, pp. 50-51). Söderholm & Wårell state regulated TPA (in general) needs unbundling of network activities from the rest of the DH system, as this ensures non-discriminatory TPA (2011, p. 744) and prevents the network owner to manipulate production prices to keep out competition (2011, p. 747). In case of local DH markets the introduction of (regulated) TPA and unbundling could lead to a situation with few new market players, resulting in an oligopoly replacing the monopoly (2011, p. 748). However, this study focuses on metropolitan areas that have the potential to be more than a small, local market for DH.

Unbundling could also lead to higher costs for administration and reporting and because of the fact that production and distribution are harder to optimise than in case of an integrated DH company (Söderholm & Wårell, 2011, p. 748). The expected higher costs for unbundling scenarios are often coupled to the size of the network where the unbundling is implemented. In a Finnish study, the expected cost increase resulting from (ownership) unbundling and introduction of TPA was estimated to be 50% of the aggregate production costs in small networks (50 GWh/annum), 10-20% for medium networks (500 GWh/a) and a more moderate 1-3% increase in large networks (5,000 GWh/a). However, with this definition of a large network, 5,000 GWh/a, which is equal to 18 PJ per annum, only one district heating system in Finland exists that meets this criterion (Pöyry Management Consulting Oy, 2018, pp. 43-53, 62).

Wissner warns for the additional administrative costs of regulating distribution grids, but also suggests (accounting or administrative) unbundling as a means to increase transparency of DH prices. He also points to the possibility of the waterbed effect, as describes by Schiff, to occur (Schiff, 2008). This could happen if price regulation is imposed only on the distribution grid, without unbundling. In this case, the (integrated) district heating company could shift costs of distribution into production prices. Without sufficient competition in the producer market, the consumer would be no better off. Administrative unbundling could at least alleviate this effect because of the cost shift would be (more) visible (Wissner, 2014, p. 67). Ownership unbundling would make it impossible for the waterbed effect to occur.

In a study commissioned by the Swedish government a committee concluded that legal unbundling should be imposed in case competition in a DH system arose through TPA (Government of Sweden, 2011, pp. 20-22). As other authors see unbundling as a necessity in combination with TPA in order for competition to develop (Söderholm & Wårell, 2011, p. 744), it can be questioned if competition will form before unbundling is enforced. Moreover, Kotlowski gives the example of legally unbundled (transmission/distribution/production) companies in the electricity and gas sectors in Europe that are thus formally independent, but in fact still hold market power. Particularly when legally unbundled companies share ownership they can be considered as a single entity that acts accordingly (Kotlowski, 2007, p. 103).

Obligatory connection

The business case for a DH system largely depends on the number of consumers that is connected to the network (Wissner, 2014, p. 65). Developing a DH system is a long-term and capital-intensive investment and (at least the distribution grid) is often considered a natural monopoly (Sandberg, Sneum, & Trømborg, 2018, p. 111). This also relates to the earlier described factors of *System size* and *Heat demand density*. With a higher number of connected consumers within the same area, the AFC (per connection) are lower (Wissner, 2014, p. 65), as is one of the characteristics of a natural monopoly. For a DH system operator, it is therefore important to realise a high number of connected consumers.

Perhaps the most straightforward method to realise high connection density is to simply mandate residents or commercial building owners in a certain area to be connected to the DH network by a regulated *obligatory connection*. There are several (European) countries and regions that have this kind of regulation. Sandberg et al. point out that in the Nordic countries, except for Sweden, obligatory connection can be imposed on buildings in a DH area. In Denmark, Finland and Norway this is the case for new buildings, only in Denmark existing buildings may also be obliged to connect to the DH network. The municipalities are the authorised organisations that decide on imposing this mandatory connection, or not (Sandberg, Sneum, & Trømborg, 2018). Other countries also have forms of mandatory connection and often the decision to impose lies with the municipal or regional government. Examples are Hungary, Poland and Germany. In Poland the obligation to connect can also be reversed, as the DH companies can be forced to connect a consumer to the network (Donnellan, Burns, Alabi, & Low, 2018, pp. 5-6).

Arguments in favour of imposing obligatory connection to DH can be found in several fields. As an obligatory connection ensures a certain amount of heat demand and in more heavily populated areas also a high heat demand density, this form of regulation can both encourage investments in DH and lower investment/financing costs, given the lowered connection risk, or *vollooprisico* in Dutch (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 67). Another reason is the benefit of economies of scale, as the system can be both larger and more dense (2016, p. 81). Obligatory connection is often combined with regulation, in order to protect the consumers that are obliged to connect (Donnellan, Burns, Alabi, & Low, 2018, p. 12). As the DH distribution grid is seen as a natural monopoly, regulation is considered necessary to protect the consumers that are forced to be connected to the incumbent monopolist against abuse of market power.

As one might imagine, there could also be resistance against this forced connection. In Denmark, public acceptance of the obligation to connect was mainly achieved through two measures. First, the transparency of the project approval process, through which new DH project have to prove their cost-efficiency and positive impact on air quality, helped the mandatory connection to DH to be accepted by the public. Secondly, the involvement of consumers in the management of DH companies ensured a focus on lowering prices and good service, facilitating support (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, pp. 17-18). In some areas exceptions to the obligation can and perhaps should be made, for example if the building owner can prove the heat demand can be met in another way and still meet the CO_2-targets (2016, pp. 8, 42, 72, 138). If these exceptions are not made possible, resistance can develop and the obligation to connect to DH can even hamper other initiatives focused on the sustainability of heating in the built environment, like energy efficient, energy neutral or passive houses, as it did in Germany (Späth, 2005, pp. 340-343). In the Netherlands there are many cases of consumers protesting the obligation to connect to a DH system. There are several reasons for this resistance, e.g. the (perceived) higher costs for DH (AVROTROS, 2017), the sustainability and energy-efficiency of houses (Opten, 2019), the lack of choice within DH systems (Moolenaar & Opten, 2019) and the lack of transparency (Van Hest & Van Laar, 2019). Several municipal and provincial governments also show resistance against obligatory connection to a DH system, especially when owned by a commercial monopolist (McDonald, Provincie Gelderland wil af van monopoliepositie Nuon op warmtenet, 2019) (De Gelderlander, 2019).

Wissner states obligatory connection is an example of a monopoly that is set by public policy. He explains this is often done to guarantee investors a recovery of and/or return on their investments. He further points out that this is a risk that an investor has to take in every market and should not be protected by law or public policy (2014, p. 68). However, the distribution part of DH is widely considered a natural monopoly. The 'creation' of the monopoly that Wissner talks about is thus applicable to DH within the wider market for heating options, as other heating technologies are excluded with a forced connection to DH. Within the DH grid a monopoly was not created, but already existing as a 'natural' monopoly. Wissner states obligatory connection should be reformed to limit the potential for abuse of market power by the monopolist (2014, p. 72). This reform should therefore be aimed at limiting the possibility for abuse of market power by the DH grid owner. This can be done to ensure competition on the producer- and provider-side of the DH system, e.g. through regulated TPA, and/or by unbundling the network operations from other DH activities.

One other argument can be found in the lack of incentive for innovation that is created by an obligatory and therefore guaranteed connection to DH. Obligatory connection can affect competition negatively. Negassi and Hung state little or no competition may lead to reduced innovation in the sector. However, they explain that in public companies innovation is not correlated with competition, where the private sector shows a positive and strong correlation between innovation and competition (Negassi & Hung, 2014). Obligatory connection that leads to a lack of competition is therefore expected to be a strong barrier to innovation in case of private ownership of the DH system, where in case of public ownership it is not.

Heat planning

Several countries have established *heat planning* policies to organise and stimulate the development of DH. Heat planning is defined and implemented by governments on different levels, varying from national to regional to local authorities. Denmark shows an example of a national government that incentivised DH development through national heat planning directives (Werner, 2017, p. 626). As Chittum & Østergaard show, the role of the Danish national government is mainly to provide frameworks and guidelines on topics like DH tariffs, energy efficiency targets and sustainability goals (Chittum & Østergaard, 2014, p. 469). It also plays an important role by providing the framework for municipalities to assess the cost-effectiveness of planned energy projects, by issuing forecasts on energy prices, demand and emission costs. This supports the socio-economic analysis of project proposals for heat production and distribution that municipalities conduct before approving such a development, or not (Chittum & Østergaard, 2014, p. 469). For decades the municipal governments have been responsible for heat planning within their jurisdiction, so they could designate a neighbourhood to be fitted with district heating or natural gas (or another heating technology). The municipalities are also in charge of approving the (proposed) activities and projects of DH companies. The city governments must ensure all projects are the most cost-effective as is possible. At the municipal level, heat planning is strongly integrated with land-use planning (Chittum & Østergaard, 2014, pp. 469-470). The *heat planning process* should not be confused with the *system design process*. These processes normally follow each other, often only separated by a procurement process, but do not overlap. The point where heat planning ends and the design process starts can roughly be considered to be the point where a set of system requirements is established and – often through a public procurement procedure, based on these system requirements – a DH company is assigned the task to design, construct and/or operate the DH system. In this report these processes will be considered as separate, but succeeding processes and will be generally referred to as either "planning process and "(system) design process". The main focus will be on the planning process.

Heat planning is also considered to help spread risk to several technologies and to be able to 'demand' better prices than individual consumers would be able to. Regular planning activity makes municipalities more flexible to respond to economic developments and changes in land use, leading to DH being a more sustainable and economic solution than the alternatives (Chittum & Østergaard, 2014, p. 471). Galindo Fernández et al. name coherent urban planning and heat mapping as one of the key success factors (KSF's) of the Greater Copenhagen DH system. They emphasize the successful application of the Danish national policy framework to the context of municipal heat planning and zoning. The project proposal that is required for every extension of or connection to the DH network is considered vital to the long-term cost-effectiveness of the DH system and involves a form of competition of DH with alternative heating options like natural gas grids of individual heat sources. These project proposals are approved or disapproved by the municipal councils (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, pp. 13-35).

The success of DH systems is considered to be influenced by the appropriate combination of regulation and planning tools, for example in the implementation of an obligatory connection to DH with planning for DH areas. Clearly defined and distributed responsibilities for planning between national and regional governments are important (Donnellan, Burns, Alabi, & Low, 2018, pp. 14-15).

3.2.3. Economic factors

The economic factors do not only relate to the relatively obvious aspects like DH prices, but also to the more 'sophisticated' factors like the distribution of roles among different stakeholders. These factors are relevant to both the system's costs and pricing and to its organisational structure. Three factors are distinguished: role distribution, ownership and price regulation, even though the last one could also be considered a regulatory factor.

Role distribution

The roles that exist within DH systems, as identified and described in section 3.1. can be fulfilled by various parties. It is necessary to distinguishing a role from a stakeholder or actor within DH. A stakeholder can fulfil one role, or several roles at the same time. This *distribution of roles* over the stakeholders is important to the functioning of the system. Tieben & Van Benthem provide an example of this, as they describe a “heating company” (*warmtebedrijf* in Dutch) that is responsible for both the infrastructure (including both transportation and distribution) and the delivery of heat to the end-user. In this case, the heating company is the stakeholder that fulfils both the role of *DSO*/*TSO* and *Provider* and, although not separately mentioned, probably also the role of *SSA*. In many cases the role of *Producer* is also fulfilled by the same stakeholder (Tieben & Van Benthem, 2018, pp. 6, 11-12). In the latter case, the heating company is fully vertically integrated, as its activities cover the entire DH value chain.

Söderholm & Wårell show there is a clear incentive for vertically integrated DH companies to not allow other parties, either producers or providers, access to their network (2011, pp. 744-745). This way, the integrated DH company protects both its market share in heat production and/or delivery and aims to maintain economic efficiency by being able to calibrate its operations. When it is the only provider and/or only producer of heat within this DH system, it is also a monopolist in the respective sub-markets. This shows the relevance of the role distribution, as a monopoly significantly influences the technical, economic and social functioning of the DH system, hence the past or even ongoing debate on unbundling of roles in DH in many countries (Söderholm & Wårell, 2011, pp. 744-750) (Tieben & Van Benthem, 2018) (Pöyry Management Consulting Oy, 2018) (Government of Sweden, 2011, pp. 21-22).

There seems to be an almost natural aversion of and resistance to monopolists. Numerous examples can be found, one will be described. In a recent case in the city of Purmerend, near Amsterdam, a small residential neighbourhood was to be disconnected from the existing natural gas grid as a result from ambitious climate policy of the Dutch national government, to be carried out by municipalities and local stakeholders. Despite some initial resistance, the majority of the consumers in this neighbourhood was voluntarily disconnected. Only six households held on to their right to receive a connection to the natural gas grid. One of the main arguments was the fact that they did not want to be dependent on a monopolist, as they currently were able to choose their own provider for natural gas and thus enjoy both their freedom to do this and in doing so the possibility to realise cost savings (AVROTROS, 2019).

In theory every role can be fulfilled by a different stakeholder, all roles can be conducted by only one party, or any other combination of roles within a single stakeholder is possible. In practice not every combination of roles might be functional; to combine for example the role of Provider and the role of SSA in one actor, without being responsible for and thus able to influence other roles, is probably not efficient. Still, several authors point to the benefits of the integration of roles for the efficiency of the whole DH system (Söderholm & Wårell, 2011, p. 746) (Tieben & Van Benthem, 2018, pp. 30-31). Especially in smaller DH networks unbundling of roles is considered inefficient (Pöyry Management Consulting Oy, 2018).

Tieben & Van Benthem state the total energy supplied in a regular DH network is considered relatively small compared to the economically efficient size of a production unit and indicate this as a reason for the monopoly of a producer, thus explaining the apparent necessity of integration. However, they take the current production units in the Netherlands into account where around 70% of DH networks are supplied by CHP-plants, which are significantly larger than other, less prevalent sources (Tieben & Van Benthem, 2018, pp. 12, 15). Therefore, it could be argued that (full) vertical integration of roles in a DH system is mainly justified in case of small networks and/or in case of CHP-plants as the most logical or only available source of heat within a system. The rise of smaller sized and less capital-intensive or even free (De Ronde, 2019) production technologies in combination with expansion and connection of DH networks could reduce the validity of the argument of inefficiency. Furthermore, the smaller production technologies, often renewable or excess heat sources, are mostly of lower supply temperatures and integrating them can therefore be facilitated by lowering DH system temperatures (Lund, et al., 2014, p. 4) (Buffa, Cozzini, D'Antoni, Baratieri, & Fedrizzi, 2019, pp. 505-508). A lower DH temperature regime could also be beneficial in case systems are larger, as the heat losses in transportation and distribution tend to be lower.

Although integration of roles is not necessarily linked to monopoly power, it often seems to co-exist. Moreover, unbundling of roles and thus undoing the integration of these is frequently mentioned as a way of breaking monopoly power. The question is therefore whether a monopoly is justified and if yes, on what parts of the DH system. A Dutch member of parliament (MP) stated an obligatory connection to a monopolist is undesirable (AVROTROS, 2019). However, it can be discussed what aspect of this is actually undesirable. As many authors explained a DH grid shows natural monopoly characteristics, the MP perhaps does not have the distribution in mind, but refers to the lack of choice and competition in production and/or delivery, which is related to the vertically integrated monopolistic DH companies in many Dutch systems. The lack of choice is also considered a barrier to the aim of connecting more buildings to DH systems, as part of the transition to more sustainable energy in the built environment (Tieben & Van Benthem, 2018, p. 19). This, again, reveals the relevance of the (dis-) integration of roles in DH; the various parts of and roles in DH systems show very different characteristics and should therefore be considered as individual entities that operate as a coherent group. Accordingly, they should possibly be managed, owned, operated and/or regulated separately, depending on the properties of the particular DH system in terms of e.g. size and production technologies.

Ownership

The issue of *ownership* could be very relevant to DH system functioning. Reviewing ownership in this section is not aimed at the (dis-) integration of different activities and joint ownership of the corresponding assets in one single party, as is discussed in *Unbundling* and *Role distribution*. This section focuses on the impact that certain characteristics of a type of ownership have on a DH system or parts of it. However, when advantages and disadvantages of an ownership type are discussed the distinction can be made between different parts of the DH system. Private ownership might for example have a different impact on heat production than on distribution.

Roughly three types of ownership can be distinguished in literature on DH;

- *Public ownership*; this type of ownership often exists in the form of DH companies that are owned by municipalities. In some occasions state-owned DH companies appear, mainly in Eastern European countries. In all cases it must concern a public body, statutory corporation, administrative organisation or governmental authority. One exception: when a DH system is owned by a company that is owned by a foreign state, it is considered as private ownership in this report, as other authors do too (Åberg, Fälting, & Forssell, 2016, p. 227). This is because of the fact that the system owner has no administrative control, direct responsibility or public interest in the area the system operates in and, the other way around, the consumer has no influence on the system owner, e.g. through voting behaviour. An example is the situation in Amsterdam, where the DH system is owned by the Swedish state-owned company Vattenfall after the take-over of the previously municipal utility Nuon (Netbeheer Nederland, 2019, p. 48).
- *Private ownership*; when DH companies are owned by private companies, regardless of if these are small local businesses or large multinational corporations, this is called private ownership. There are examples of large, publicly traded companies with many energy-related activities, of regional companies that focus on DH and of local private parties that own one single DH system in a small municipality. As mentioned above, a DH system that is owned by a foreign public body is considered privately owned.
- *Cooperative ownership*; also called collective ownership or 'consumer-owned' DH company. As the name implies the heat-consumers own the system they are connected to through a collective organisation. This form of ownership is very common in the Danish DH sector, both for distribution of heat (Rønne & Nielsen, 2019, p. 226) and for production, especially in smaller plants (Danish Energy Agency, 2017, p. 8). As the other ownership forms, cooperative ownership can be applied to the whole, integrated DH system or to parts of it, like distribution and delivery or production, as is common in electricity production through wind energy.

Naturally, there are many variations on these basic types, like combinations of public and private ownerships in the form of public-private partnerships or PPP (Zeman & Werner, 2004). Ownership of DH systems or parts varied between regions and between countries. Sometimes ownership types are promoted or discouraged by regulation or policy, sometimes there simply is little to no regulation regarding ownership.

In the majority of countries DH systems first developed under public ownership. Municipally-owned or even state-owned systems were very common in Scandinavia, the Baltic states and Eastern Europe. In the Netherlands several DH systems are currently in private hands, but were developed by municipal utilities that, through mergers, acquisitions, regulation and unbundling ended up in private energy companies (Akerboom, Van der Linden, & Pront-Van Bommel, 2014, p. 4). Also in other countries DH systems were developed by public organisations and later, especially during the '90's and '00's, fully or partly privatised, like in Sweden, Estonia, Germany and Poland, with varying degrees of success (Magnusson, 2016, pp. 201-202) (Söderholm & Wårell, 2011, p. 742) (Zeman & Werner, 2004, pp. 10, 14-15, 19-20) (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 40).

After privatisation in Sweden the new owners were large (sometimes foreign) private energy companies. Swedish deregulation has shown that liberalisation and resulting private ownership in natural monopoly situations can lead to price increases of up to 50%, leading to a rising demand for third-party access (Magnusson, 2012, p. 450). Later several private companies came to large-scale disinvestments in many of their DH systems, mainly selling these off to other private parties. These large companies focused on geographically and economically strategic places and sold the DH systems that did not meet the criteria for return on investment (ROI) or long-term strategy, sometimes even in bundles to foreign private equity parties, ignoring the possibility for re-municipalisation despite interest of some municipal governments. It was suggested that a lack of citizen participation and representation resulted from this and private companies were thought to be cherry-picking DH systems with the best business case (Magnusson, 2016, p. 205). There even are examples of foreign private investors that put some small DH systems into bankruptcy because of a lack of experience with the local Swedish context (Werner, 2017, p. 426).

In Denmark the current situation is characterised by the near absence of privately owned DH systems. Denmark has a long tradition of cooperatives in different parts of society and industry (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 35). This is also visible in the DH sector, as 83% of the Danish DH systems are cooperatively owned, accounting for 34% of the total heat supply. A much lower share of 12% of the systems was owned by municipalities, although these systems are evidently significantly larger as these accounted for 58% of the total heat supply. A very modest 2% of DH systems are commercially owned, with a 5% share in the total heat supply (Rønne & Nielsen, 2019, p. 226). Given these numbers, it can be said that, at least in Denmark, cooperative ownership is correlated with smaller sized systems and municipal ownership with larger systems. The alignment of interests between different stakeholders in the DH sector is mentioned as one of the KSF's of the Greater Copenhagen DH system and is thought to be facilitated by the non-profit regulation and the ownership structure of DH companies in Denmark (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 24).

Above ownership types are discussed in the context of an integrated DH system, with ownership of all parts of the system combined in one organisation. It is not necessarily the case that all parts, from production facilities to distribution networks are owned by one party, see *Unbundling*. Furthermore, other stakeholders might also fulfil a role in the system, although they do not necessarily own any physical system elements. Their ownership structure might be relevant too for the way they perform their role. An example would be the role of *Provider*, as described in section 0, especially if this role is unbundled from the roles of *Producer*, *TSO* and *DSO*.

In the Netherlands the debate about the distribution of these roles is ongoing and the ownership structure is part of this discussion. There are different forms of combined ownership and of partnerships within the DH value chain. Still, the majority of the Dutch large DH systems show integrated ownership, either the whole chain from production to delivery, or with only separate ownership of a (only) heat source. The Ministry of Economic Affairs and Climate is currently working on new legislation for DH, aiming to more clearly define the roles and responsibilities of public and private parties and to stimulate a market order that contributes to a more affordable, reliable and sustainable heating sector (Netbeheer Nederland, 2019, p. 48). Calls for public ownership of DH transportation and distribution networks have been increasing. Arguments in favour of this are concentrated around three topics; decreasing uncertainty with potential heat producers and providers, lowering costs of financing and fair competition between DH and natural gas through socialisation of networks costs. Public ownership of transportation and/or distribution is thought to be able to stimulate investments in DH systems (Hoogervorst, 2017, p. 71) and could prioritise public interests in investment decisions (Tieben & Van Benthem, 2018, p. 30). Hoogervorst concludes that public ownership of transportation/distribution is not an absolute necessity, but it can eliminate barriers and accelerate investments (2017, p. 71). Tieben & Van Benthem conclude that, in case of unbundling, public ownership can lead to lower financing costs, improved continuity, possible extra investments, prioritisation of sustainability and possibly improved alignment between DH and other heating technologies when these are also owned by the same public DH owners. However, Tieben and Van Benthem argue that the disadvantages of unbundling the ownership of distribution from production/delivery outweigh the benefits of public network ownership. However, they state the benefits could be significant enough in case of large DH systems (Tieben & Van Benthem, 2018, pp. 34-36). Besides, they discuss public ownership in the context of full unbundling, not in case the whole system is public or distribution and delivery are integrated in a public owner.

The type of ownership may also have an influence on efficiency of and innovation in the DH company. As discussed under *Unbundling*, *Price regulation* and *Obligatory connection* a lack of competition may negatively affect DH in several different ways. Low competition is thought to hamper innovation (Negassi & Hung, 2014). However, Negassi & Hung also explain there is no correlation between competition and innovation in public companies, but these are positively and strongly correlated for private companies (Negassi & Hung, 2014). Therefore, it could be argued that public ownership is more appropriate than private ownership in (sub-) sectors where competition can be hard to achieve or simply is unrealistic, like in case of a natural monopoly. As discussed in section 3.2.2 the distribution and transmission of DH can be considered a natural monopoly. Consequently this may be a compelling argument for public ownership of distribution and/or transportation networks in DH, whether they are unbundled or not. Conversely, sub-markets that are not considered a natural monopoly could benefit from innovation through competition between private parties.

Concluding, the three main ownership types each have a different impact on the DH system design and functioning:

- *Public ownership* is probably the most common form of ownership in DH. In the majority of countries DH systems developed under municipal ownership and in many cases this remains until today. Public owners tend to prioritise public interests, generally accept a lower profit margin than private companies, have a longer horizon and in some cases have easier/cheaper access to the capital markets. It could be argued that distribution is considered a natural monopoly and should therefore be publicly owned, as competition is hard to achieve and this would hamper innovation in case of private ownership.

- *Private ownership* exists in most countries, although in some it is more common than in others. During periods of increased privatisation many DH systems were sold to private parties by municipalities, for example in Sweden and the Netherlands between 1995 and 2005. Other DH systems were developed by private companies from the start. Private ownership of DH systems is sometimes associated with lower citizen participation and representation and with cherry-picking of DH areas with a favourable business case.
- *Cooperative ownership* shares several of the benefits of public ownership, like prioritisation of public interests, lower acceptable profit margin and a longer horizon. When cooperatives are also financially backed by governments (through) policy they can have easier access to capital markets. They can have the additional benefit of higher citizen participation and public support. Cooperative ownership is more often present in small DH systems, compared to municipal (public) ownership.

Price regulation

The *regulation of 'price'* in DH can point to different methods. Wissner distinguishes both price regulation of the distribution grid and regulation of consumer prices. The first focuses on regulation of the price a distribution grid owner charges for the service of distribution of thermal energy. This is done to protect the consumer from excessive prices, as the DH distribution grid can be seen as a non-contestable natural monopoly (2014, pp. 66-67). This form of price regulation could be combined with (administrative) unbundling, which helps to clearly quantify the precise costs of DH distribution and prevent the occurrence of the earlier mentioned waterbed effect. The regulation of the distribution service fee can be implemented in several ways, e.g. as a price cap or as a cost-based pricing method.

The latter method, the regulation of consumer prices, is focused on the price the end-user pays for the delivered heat. This way of regulating is very relevant in case of integrated district heating companies, as the regulated retail price covers costs for both production and distribution (and other cost factors of the integrated DH company, like sales and administration). Consumer prices can be regulated *ex-ante* or *ex-post*:

- *Ex-ante price regulation*; this form of price regulation attempts to influence the (formation of the) price before it is actually established and set in the market. Ex-ante regulation is considered a more strong form of regulation, compared to ex-post price regulation, as it intervenes more heavily in the market.
- *Ex-post price regulation*; when a price control is only carried out after prices are set by the market, it is considered ex-post regulation. When there is suspicion of abuse of market power, like price mark-ups, and prices are subsequently controlled, this is an example of ex-post price regulation.

Söderholm & Wårell see ex-ante price regulation as the (only) reasonable option in case the whole DH system shows natural monopoly characteristics (2011, p. 751). Wissner also views ex-ante regulation as a tool for consumer protection in case the (integrated) DH company has a monopoly. He mentions three prerequisites for ex-ante regulation, being the existence of substantial barriers to market entry, no trend towards development of competition and ex-post regulation being insufficient to reach competition (2014, p. 69). Ex-post regulation can be an alternative to ex-ante regulation, mainly in case there is (at least some) competition in the market. In this case retail price regulation could be harmful and put a constraint on competition (2014, pp. 70-71). In many DH systems there is little to no competition, making ex-ante price regulation a logical consideration.

Different countries show different examples of price regulation, in combination with other regulatory measures. For small DH systems where competition was hard to establish and DH companies remained vertically integrated, a Swedish government committee suggested regulation of the price of distribution (so not retail price regulation), combined with administrative unbundling of the distribution grid (Government of Sweden, 2011, pp. 20-22). In the Netherlands all DH systems are subject to retail price regulation based on a reference to the price an average consumer pays for residential heating with natural gas. This is a form of ex-ante regulation, setting a price cap on the retail price for heat through DH (Autoriteit Consument & Markt, 2018, p. 3).

3.2.4. Societal factors

This last category considers factors that relate to society and directly affects people. Societal factors are – probably more than previous categories – influenced by other factors. For example the factor of transparency is almost as much a regulatory or policy factor as it is a societal factor, because the degree of transparency – for example of DH tariffs or procurement processes – can be stimulated by legislation or policy frameworks. Still, as the effects of these factors are very visible and impact society as a whole, they are classified as a separate category.

Citizen participation

Various concepts are related to or even synonyms for the phenomenon of *citizen participation*, e.g. energy cooperatives, local ownership, citizen involvement, social participation or community energy (Hatzl, Seebauer, Fleiß, & Posch, 2016, p. 58) (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 18) (Mazhar, Liu, & Shukla, 2018, p. 432). Citizen participation is mainly of influence on transparency, understanding (e.g. technical and economical), empowerment, resilience/self-reliance (Mendonça, Lacey, & Hvelplund, 2009, pp. 394-395), awareness (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 133) and public support (Hoogervorst, 2017, p. 49) and these factors are also of influence to each other.

In different renewable energy fields forms of citizen participation are present. Involving citizens can be done for several reasons and in many ways. Galindo Fernández et al. claim DH systems have become more open to stakeholder participation and cooperation over the years (2016, p. 137). Numerous authors emphasize the importance of social or citizen participation. Mazhar et al. state citizen participation is necessary in all stages of the development and operation of a DH system (2018, p. 432). Others mention the relevance of citizen participation to improve climate awareness and the possibility for participation on the investment side through community based ownership, e.g. in cooperative DH structures (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, pp. 133, 138), although other authors state citizen participation is even more important than consumer (co-) ownership of DH systems (Buffa, Cozzini, D'Antoni, Baratieri, & Fedrizzi, 2019, p. 507). Still, cooperative DH ownership structures can also be beneficial for endorsement and understanding of DH systems by its users (2016, p. 139). Galindo Fernández et al. point to the influence citizen participation can have in creating public acceptance. Regulatory measures like imposing an obligation to connect to the DH system can benefit from involvement and participation of citizens as this is expected to stimulate acceptance of these regulations (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, pp. 17-18).

Involvement of citizens in the decision-making process around DH can increase the public support for the specific DH system and for DH in general. However, it is important to not only let citizens provide input, but also to ensure their interests are protected and included. As DH companies are expected to be better able to map and highlight their interests than citizens are, the latter should be safeguarded by municipalities, e.g. in drafting procedures that guide a fair decision-making process (Hoogervorst, 2017, pp. 49-50). As described under *Planning* in section 3.2.2, municipalities are often the appropriate and therefore designated parties to carry out the heat planning process. A logical addition could be to also assign municipalities with the task of overseeing and guiding the heating system design and tendering process and making them responsible for guarding the interests of consumers through citizen participation. This is more or less the strategy the Dutch national government adopted in their most recent climate policy (Rijksoverheid, 2019, pp. 216-219).

Lessons can be learned from consumer-owned renewable DH cooperatives in different countries. Participation by citizens is often visible in smaller towns and rural communities. Citizen participation is considered an essential success factor in sustainable DH projects in these areas, as it increases acceptance and the willingness to connect to the system. Usually these cooperatives aim to recover costs made for renewable energy-based DH and are not interested in making profits (Pauschinger, 2016). However, it might be that not all consumers are equally interested in participating in a DH system. More than that, it could be the case that some citizens do not want to cooperate at all. Still, having only the possibility to participate could improve confidence, trust and support for the DH system. Perhaps there is an active minority of citizens that participate and in doing so they could encourage the passive majority in having confidence.

Concluding, citizens can participate on different levels; they can create awareness on (sustainable) DH, lobby for consumer interests, participate in local or regional heat planning, participate in collective commissioning and development and engage in collective ownership (Schwencke, 2019, p. 75). The level of participation depends on the local characteristics. Participation can, if executed appropriately, enhance understanding, resilience and support in DH through increased awareness, empowerment and transparency (Mendonça, Lacey, & Hvelplund, 2009, pp. 394-395) (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 133) (Hoogervorst, 2017, p. 49).

Consumer representation

Even though closely related and often influencing each other, citizen participation and *consumer representation* are considered not exactly the same. When discussing consumer representation, this mainly regards to the way and degree consumers of DH systems are represented within the DH organisation(s), especially within the governance structure and decision-making processes.

Roughly two ways can be distinguished of consumer representation in decision-making processes regarding DH systems: direct and indirect representation (Chittum & Østergaard, 2014, p. 470). Direct representation mainly concerns direct election of consumer representatives by all end-users connected to the DH system in question, proportional to their size. This can occur as a result of direct ownership of (parts of) the DH system – often via citizen cooperatives – or through legislation that demands a certain degree of influence on the DH companies, like the Danish Heat Supply Act does (Rønne & Nielsen, 2019, p. 235). Indirect representation primarily follows from municipal ownership of the DH company, where consumers are represented via their citizenship of that municipality and they can influence their representatives through elections for the municipal council (Chittum & Østergaard, 2014, p. 470).

The degree to which DH-consumers are represented within their DH company can differ significantly per country, per region and even per system. Chittum & Østergaard state the needs of consumers of DH are represented well in Denmark, although the authors refer to the heat planning and procurement processes for this. However, they also state consumers are permanently represented in the governance of their DH company through elected representatives, which might lead to stronger confidence in decision-making (Chittum & Østergaard, 2014, p. 470). Danish consumer representation via directly or indirectly elected representatives is also linked to non-profit DH companies (Danish Energy Agency, 2020). Of the roughly 400 DH companies in Denmark, around 350 are cooperatively owned and thus have a form of direct consumer representation, the other 50 – which on average operate larger systems – are municipally owned and thus show an indirect representation (Jessen, 2017, p. 2). In the Netherlands consumer representation is much less prevalent, as there are only a few dozen citizen initiatives on DH, roughly five citizen cooperatives or foundations and just one cooperatively-owned company that actually operates a DH system (Schwencke, 2019, pp. 75-76). Even though the number of citizen initiatives on DH is rising in the Netherlands, it almost always regards feasibility studies or similar activities. Indirect representation of consumers in DH companies can be found more often in the Netherlands, although unbundling in the electricity sector led to DH systems becoming part of the electricity-producing and providing companies that were subsequently privatised in the following decade.

Transparency

Greater *transparency* can be beneficial to a DH system. Transparency can exist on many levels and be promoted in several ways. Tieben & Van Benthem explain the role that unbundling of distribution from production and retailing activities can play in increasing transparency of the DH cost structure (2018, p. 37). Improved cost transparency through (accounting) unbundling could increase pressure to offer fair DH prices (Wissner, 2014, p. 72). It could also stimulate investments in (new) DH grids (Tieben & Van Benthem, 2018, pp. 29-30) and could facilitate the connection of new heat sources, through non-discriminatory TPA (Söderholm & Wårell, 2011, p. 750). Transparency and its effects can be enhanced when not only administrative, organisational or legal unbundling is imposed, but ownership unbundling is implemented (Tieben & Van Benthem, 2018, pp. 29-30). Hoogervorst points out that the aversion to being surrendered to a (vertically integrated) monopolist could be alleviated by being transparent about DH costs and tariffs, because this might for example lower the desire for or demand of being able to choose a heat provider (Hoogervorst, 2017, p. 46).

Between 2002 and 2005 a special District Heating Commission investigated several issues regarding DH in Sweden, like unbundling, TPA, transparency and price regulation. The District Heating Act that was subsequently introduced by the Swedish government rejected several proposals for unbundling, TPA and price regulation, but it incorporated 'soft' regulation on transparency, in the form of the obligation to publish annual balance sheets and profit and loss statements for all DH activities (Werner, 2017, p. 426).

Galindo Fernández et al. also mention the importance of transparency in energy planning procedures to stimulate competition and stakeholder participation, but also to increase public support (2016, pp. 7-8, 17). In the recently published Climate Accord (Dutch: *Klimaatakkoord*) of the Netherlands transparency is mentioned as an important factor in creating public support and acceptance. Especially a transparent decision-making process is thought to be important (Rijksoverheid, 2019, p. 216). Galindo Fernández et al. conclude that transparent procedures are crucial and municipalities should also aim to clarify the principles on which they base planning decisions. An example can be found in experiences in Denmark that show this indeed is important, as the obligatory connection in the Greater Copenhagen, one of the KSF's of the system, benefitted from large public acceptance that was mainly due to transparency in the DH design and approval process (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, pp. 17-18, 137).

Where several Scandinavian countries show a certain degree of transparency in DH planning processes and heat prices, some systems in other countries prove to be examples of what a lack of transparency can lead to. In the Dutch city of Nijmegen, very little transparency in DH prices and consumer bills led to resistance and distrust towards the DH company. Combined with little confidence in the sustainability of the heat provision, the monopoly position of the incumbent DH company and the obligation to be connected to and purchase heat from the system, this resulted in an investigation into the planning procedure and regulatory framework of the DH system. The investigation showed very little clarity and consistency in the planning and tendering procedure and concluded the decision-making process was inconsistent, inimitable and untransparent at crucial moments (Van Hest & Van Laar, 2019).

Concluding, there are roughly three forms of transparency that can be distinguished:

- *Transparency in the composition of DH end-user prices*; this includes information on the price/cost allocation of DH over the different activities of production, distribution and delivery. This form of transparency could increase pressure on DH prices, stimulate investments in DH and facilitate non-discriminatory TPA.
- *Transparency in DH operations and the associated costs*; this is different from the composition of the end-user price, as that focuses on the allocation of parts of this price to different activities. Transparency in operations and costs for example highlights the efficiency of heat production or distribution and could stimulate competition within these sub-markets, either directly or through benchmarking.
- *Transparency in the heat planning process*; municipalities and other local or regional authorities are widely considered to be the designated parties to implement this. This could both stimulate competition and could increase public support and stakeholder participation.

3.3. Conclusion

There have been numerous studies on district heating systems over the years. Although these often focus on only one or a few different stakeholders or factors. This chapter describes several different roles that can be fulfilled in DH systems by various stakeholders. It also distinguishes sixteen factors of DH system functioning, spread over four categories. In doing so, the first sub-question is answered.

SQ1	What are factors in the functioning of district heating systems and which roles can be distinguished in existing literature?

First, six main roles in DH systems are described. These roles each perform activities that are directly related to the value chain of the DH system; from production to consumption. The roles – *Producer*, *TSO*, *Heat load planner*, *DSO*, *Provider* and *Consumer* – are all considered part of this value chain, although in greatly different ways. As stated before, each role can be fulfilled by a separate stakeholder, or multiple roles are performed by one (integrated) party. The extent to which these roles are fulfilled by different parties and what the other characteristics of these organisations are, is expected to also influence the functioning of DH systems. Besides the six main roles, active in the DH value chain, there also are a few other roles to be fulfilled. Of these the municipal and national government are the most important, as they are considered to be quite influential and to be performing supporting, but vital activities for the functioning of the DH sector as a whole and specific systems in particular.

Besides these role descriptions, fifteen factors are identified that influence the way a DH system functions. These factors are divided in four categories; *technical and physical factors*, *regulatory and policy factors*, *economic factors* and *societal factors*. These factors do not only influence the physical system itself, but also have an impact on more abstract elements of a DH system, like the price consumers pay or whether or not they can be legally forced to connect to the system. Many earlier studies focus on one factor or a few factors within the same category. This research will consider all of these different factors and investigate their relevance and impact. The sixteen factors that together shape DH system functioning provide a solid base for describing and categorising DH systems in the following chapters, especially in the establishment of system design types in chapter 9.

4

CASE STUDY DESIGN

A multiple single-outcome study on two European cases

Ørsted's *H.C. Ørstedsværket* CHP-plant, Copenhagen

The previous chapter established a solid foundation for the coming research steps by reviewing available literature and focusing on factors in district heating system functioning and the roles that are fulfilled in such a system. A multiple single-outcome study with two cases will build on the information that is gathered in chapter 3. This chapter will explain the approach that is adopted to conduct this case study. The selection of the two cases will be explained (section 4.1), followed by the data collection (4.2), the selection of participants (4.3), the case protocol (4.4) and the analysis of the information that is collected (4.5).

4.1. Case selection

The selection of the cases that are studied will follow a methodological approach. In section 4.1.1 the method of this selection is described. Section 4.1.2 will elaborate on the selection itself and the cases that result from this procedure.

4.1.1. Selection method

As already discussed in chapter 2 of this thesis, the research will have a geographical focus on metropolitan areas (section 2.3.3) in Europe (2.3.4). The selection of a 'population' from which the cases are drawn is needed first, as an appropriate population avoids unnecessary and irrelevant variation and defines the limitation for generalising the research findings (Eisenhardt, 1989, p. 537). The population for this research will thus be constituted by European metropolitan areas that have DH systems of varying sizes, ages, sources, regulations and other characteristics.

Regarding the definition of the term *case study*, Gerring (2006, pp. 709-710) distinguishes the 'classical' case study, described as *"narrowly scoped studies that reflect upon a broader population"*, from the concept of the single-outcome study, defined as *"studies that investigate a bounded unit in an attempt to elucidate a single outcome occurring within that unit"*. When the study in question embraces different propositions and does not have a clearly defined outcome, i.e. there are multiple variables that define the outcome, Gerring classifies the study as a *multiple single-outcome study* (2006, p. 712). He also states that it is quite typical to mix these techniques. These (multiple) single-outcome studies are still described as a style of case study, although different from the classical and more narrow definition (Seawright & Gerring, 2008, p. 296).

Given the limited time that is available for conducting research and writing a graduate thesis, two cases will be selected. In order to select these two cases, the right case selection technique has to be applied, as random selection is not a necessary, preferable (Eisenhardt, 1989, p. 537) or even viable approach (Seawright & Gerring, 2008, p. 295) when the number of cases that is to be studied is small. According to Seawright & Gerring a 'purposive' method seems more appropriate. When the goal of the case study is to build theory on its outcomes, instead of using case studies to obtain statistical evidence on a population from which the cases are selected, not random sampling but the method of theoretical sampling is the right selection technique (Eisenhardt, 1989, p. 537).

In selecting, or 'sampling' the cases a distinction needs to be made between theoretical sampling, as described by Eisenhardt (1989) and purposive sampling, as described by Bryman (2012). Both seem to be the same, but as Bryman points out theoretical sampling is only one form of purposive sampling. Hood (2007, pp. 151-152) points out that many authors falsely describe their qualitative research as using 'grounded theory', where they often just use (a form of) the 'generic inductive qualitative model' (GIQM). Hood states that the GIQM uses purposive sampling, theoretical sampling is applied in grounded theory. Furthermore, Bryman emphasizes the importance of making a distinction between the levels of sampling, which is very relevant for sampling in qualitative research. When using a multiple case study design *"the researcher must first select the [...] cases; subsequently, the researcher must sample units within the case"* (Bryman, 2012, p. 417). This double case study will therefore take these two levels into account when selecting two cases ('context') in section 4.1 and selecting interview candidates ('participants') within these cases in section 4.3. For both levels purposive sampling seems more appropriate, as this research is expected to be open-ended and emphasizes the generation of concepts and theories, but does not bring the iterative process of data collection that is repeated until theoretical saturation, like in grounded theory (Bryman, 2012, p. 422). In this study purposive sampling is employed in a fixed manner, with selection criteria that are established 'a priori'.

The way Eisenhardt describes theoretical sampling seems to have many features of purposive sampling as described by Bryman. In most of the examples Eisenhardt gives in her paper, the iteration in case selection that is typical to theoretical sampling, as part of grounded theory, is missing. It is therefore assumed that she does not differentiate between theoretical sampling and purposive sampling, exactly as Bryman (2012, p. 422) describes. For that reason Eisenhardt her notion of theoretical sampling is taken as similar to purposive sampling in qualitative research. As Eisenhardt (1989, p. 537) states, the goal of 'theoretical sampling' is to choose cases that can help to build and extend the new theory. The visibility and observability of the element of interest is important to the research, especially when the number of cases is small. In order to ensure this observability, choosing relatively 'extreme' cases could be an option for the case selection (Pettigrew, 1990, p. 275). This *Extreme Case* method selects a case based on an extreme value on the outcome and/or variable of interest (Seawright & Gerring, 2008, p. 301), where other variables show more average outcomes. Another way to ensure visibility of the elements of interest is to choose *'polar types'* (Eisenhardt, 1989, p. 537) like examples with high and low performance (Pettigrew, 1990, pp. 275-276).

A third option is the *Most-Similar* method, where a minimum of two cases is chosen, which are similar on most or all variables, but vary on the 'outcome' of the case. If the researcher does not have a presumption of the causes of the case outcome, a second case with a deviant outcome but similar values for all variables is selected (Gerring, 2006, p. 723). Then the researcher closely studies the two selected cases, trying to find differences that could explain the divergence in the case outcomes. When the researcher does have a feeling for what causes the distinct outcomes, the cases are selected on variance in the case outcome and variance on the variable that is thought to influence the heterogeneity in case outcomes (Gerring, 2006, p. 723) (Seawright & Gerring, 2008, p. 304).

This research is aimed at providing insight in the DH system design features that facilitate the transition to a sustainable heat provision in metropolitan areas. Because of the small number of cases that will be studied (and also because not many large DH systems in metropolitan areas in Europe exist) and the lack of knowledge on factors that stimulate sustainability in metropolitan DH systems, the adopted method is not a 'classical' case study and does not include random sampling of cases. The approach will be a *Multiple Single-Outcome Study*, including both within-case analysis (of physical, economic and regulatory factors) and cross-case analysis (of stakeholders, requirements and planning process of the two DH systems), similar to the approach employed by Endl (2017, p. 6). Following Endl's approach, this method would provide insight on the multiple (range of phenomena, i.e.: factors) single outcome (DH system design). On both the 'context' and the 'participant' level, a purposive sampling technique will be applied.

4.1.2. Selected cases

As the research is conducted in the Netherlands and performed at Alliander, a Dutch publicly-owned DSO for electricity and natural gas grids that is responsible for approximately one third (5 million customers) of the Netherlands, it seems rather obvious to include a Dutch case in the research. Furthermore, the Dutch national government has reached agreements with societal organisations, businesses and other organisations to stimulate DH and is developing new legislation and heating strategies (Rijksoverheid, 2019). There is only a handful of metropolitan areas of a significant size (over one million inhabitants). The city of Amsterdam has been actively working on a heating strategy for the metropolitan area (Amsterdam Economic Board, 2016) and expects to increase the current DH systems to about half of the city's buildings. The Amsterdam metropolitan area also falls within the Alliander service area. Therefore, the metropolitan area of Amsterdam is (pre-) selected as the first case for the multiple single-outcome study (from now on called *(double) case study*, although not the 'classical' case study form is meant). Pre-selecting one of the two cases is common in (multiple) single-outcome analysis that uses the Most-Similar method (Gerring, 2006, p. 723).

The description of 'case selection' or 'sampling' approaches by Eisenhardt, Gerring, Seawright & Gerring, Pettigrew and Bryman are very well comparable and can be considered as equivalent. As Seawright & Gerring (2008, p. 305) state, the matching procedure that goes with the Most-Similar technique is not an exact science, as it in practice is impossible to have precisely the same scores on certain variables. Furthermore, they illustrate that it is common to mix case selection methods (Seawright & Gerring, 2008, p. 306). This is an important observation, as this study aims to adopt a two-step case or 'context' selection procedure. First, the metropolitan area that will serve as second case needs to be similar to the Amsterdam area on general characteristics. The two cities cannot be too different in terms of size, climate, density and building stock and should be relatively comparable on economic and governmental subjects. Therefore, the first step of the selection procedure will be based on the Most-Similar method. Only the status of the heating sector in the two areas needs to be different.

The second step will compare the cities that meet the criteria of the first step on the characteristics of their DH sector. For this, elements of the Extreme Case method will be followed, where the aim is to select a city with an extraordinarily well-developed DH sector (the outcome), measured in terms of size (number of consumers and energy supplied) and sustainability, as well as elements of the Diverse Case method (comparable to the polar types mentioned by Eisenhardt), where the objective is to achieve maximum variance on relevant factors in the DH system, like certain regulatory elements (Seawright & Gerring, 2008, pp. 300-302). This way, the outcome of the second case stands out compared to other European metropolitan areas, including Amsterdam, and the different elements of the DH system show variation among the two cities.

Based on desk research for both the first and second selection step, the city of Copenhagen was chosen as the other case to be studied. Table 1 shows a comparison of Amsterdam and Copenhagen on general characteristics. The two cities are rather similar on the displayed features, divided in geographical, physical, economic and political topics.

GENERAL CITY CHARACTERISTICS	AMSTERDAM	COPENHAGEN
Geographical characteristics	**Situation**	**Situation**
Location at/near sea	Near North Sea	At Øresund, between Kattegat and Baltic Sea
Close to river(s) and water bodies	IJsselmeer, city canals local lakes, Amstel river	Local lakes and small rivers
Temperate oceanic climate	Köppen: Cfb type	Köppen: Cfb type
Physical characteristics	**Situation**	**Situation**
Between 600,000 and 900,000 inhabitants in city	City population: 862,965 (2019)	City population: 633,449 (2020)
Between 2 million and 2.5 million inhabitants in metro	Metro population: 2.7 million (2019)	Metro population: 2.1 million (2020)
Old city / large share of older buildings (100+ years old)	Founded in 1275	Founded in 1167
Densely populated and built	5,214 inh./km^2	4,400 inh./km^2
Extensive and dense (public) transportation network	Extensive train, tram, metro and road infrastructure	Extensive train, metro and road infrastructure
Economic characteristics	**Situation**	**Situation**
Large business district	ZuidAs, Bijlmer, Sloterdijk/Teleport, Omval, Centrum	Indre By, Sydhavnen
High real estate prices	€4,610 / m^2 (2018) and €7,615 / m^2 in city centre	€5,236 / m^2 (2018) and €6,286 / m^2 in city centre
Industrial area(s)	Westpoort, IJmuiden, Aalsmeer	Refshaleøen, Nordhavn, Avedøre Holme
(large) Seaport	Port of Amsterdam	Copenhagen Malmö Port
Highly educated population	108,000 students	94,000 students
Large international airport	Amsterdam Airport Schiphol (71 million/year)	Copenhagen Airport (30 million/year)
Political characteristics	**Situation**	**Situation**
Progressive (local) government	Social democrats, green party, liberal democrats	Social democrats, socialists, liberal democrats
Democratic and/or cooperative governance structures	Elected city council, citizen initiatives in many fields	Elected city council, many cooperative structures

Table 1 – Comparison of Amsterdam and Copenhagen on general characteristics in four categories

Because the cities are quite well comparable, the conditions are created for a proper study of the influence factors in DH system functioning have on the system design, as the 'outcome' is not distorted by other, perhaps more general elements of cities. This also creates the right conditions to make a 'pure' comparison on DH system features and select a second case based on elements of the Extreme Case method and the Deviant Case method, resulting in the choice for Copenhagen.

DH SYSTEM CHARACTERISTICS	AMSTERDAM		COPENHAGEN		COMPARISON
Technical and physical characteristics	**Indicator**	**Score**	**Indicator**	**Score**	**Difference**
Size - *number of consumers*	ME	3	VH	5	2
Size - *energy supplied*	ME	3	VH	5	2
Sustainability	LO	2	HI	4	2
Regulatory characteristics	**Indicator**	**Score**	**Indicator**	**Score**	**Difference**
Unbundling	VL	1	ME	3	2
Third-party access	LO	2	ME	3	1
Price regulation	ME	3	VH	5	2
Obligatory connection	ME	3	HI	4	1
Heat planning	LO	2	VH	5	3
Economic characteristics	**Indicator**	**Score**	**Indicator**	**Score**	**Difference**
Role distribution (e.g. monopolies)	VL	1	HI	4	3
Connection % (city-wide)	LO	2	VH	5	3
Ownership type (VH: public, VL: private)	VL	1	VH	5	4
Cost socialisation	LO	2	HI	4	2
Societal characteristics	**Indicator**	**Score**	**Indicator**	**Score**	**Difference**
Participation	VL	1	VH	5	4
Transparency	LO	2	VH	5	3
TOTAL SCORE		**28**		**62**	**34**
Average		***2.0***		***4.4***	***2.4***

Table 2 – Comparison of Amsterdam and Copenhagen on specific DH system characteristics in four categories

Copenhagen has a well-developed DH system (outcome) in terms of size and sustainability and its DH system characteristics (variables) deviate significantly from the Amsterdam DH system, as can be seen in Table 2. Both cities are assessed on several technical, regulatory, economic and societal characteristics of their DH systems. Indicators are *Very low* (VL), *Low* (LO), *Medium* (ME), *High* (HI) and *Very High* (VH) and scores range from 1 to 5 respectively. This results in a score of 28/70 for Amsterdam, 62/70 for Copenhagen and an average difference on the variables of 2.4/5.

4.2. Data collection

To be able to answer sub-question 2 and especially sub-question 3 and 4 it is necessary to gather the right information and perform the data collection in an accurate way. Therefore a brief data collection strategy is illustrated in this section. Very relevant to this strategy are the three principles of data collection that Yin (2003, pp. 97-106) describes. These principles can help establishing the construct validity and reliability of the case study evidence, which are two of the four commonly used quality criteria for research designs (Yin, 2003, pp. 33-39). The three principles are described as follows:

a) *Using multiple sources of evidence*
b) *Creating a case study database*
c) *Maintaining a chain of evidence*

The data that is used in the case study needs to originate from at least two types of sources *(principle a)*. This creates the possibility of triangulation of data sources, which is likely to lead to more convincing conclusions in a case study. This study uses two types of sources as described by Yin (2003, pp. 85-96):

1. Documentation (e.g. research papers, reports, news articles)
2. Semi-structured interviews (with stakeholders and experts in DH sector)

The choice for documentation is based on the relatively wide availability of research reports (for example by government agencies and research institutions) and news articles (both popular and professional media) on the DH sector in the two cases. Documentation can serve as a stable, broad and potentially detailed source of data and is likely to be relevant to every case study topic. However, the researcher needs to be aware of the risks of inaccuracy and bias and needs to be critical in interpreting the data in these sources (Yin, 2003, pp. 85-88).

Interviews are one of the most important sources of case study information and will appear to be guided conversations rather than structured queries, according to Yin (2003, p. 89). Interviews in qualitative research are, compared to interviews in quantitative research, much less structured and flexible, responding more to the direction the interviewee is heading, interested as the qualitative researcher is in the interviewees point of view and view on relevant and important topics, seeking more rich and detailed answers (Bryman, 2012, p. 470). The method of semi-structured interviewing is chosen because of its relatively flexible nature, the ability to pick up on important things interviewees say and the iterative process of refinement of the interview guide based on interviewees' thoughts and responses to the open-ended questions. However, the interviewer follows the interview guide at least to a certain extent, especially as this regards a multiple-case study that needs a certain degree of structure in order to ensure comparability (Bryman, 2012, pp. 471-472).

Creating a case study database is another important principle *(b)*, related to the organisation and documentation of the retrieved data. The case study database should enable other researchers or readers of the final report to independently inspect the (raw) data that the study's findings are built on and thus increase the reliability of the case study (Yin, 2003, pp. 101-105). The two case reports are built on the two sources of data that are mentioned above and are included in this thesis report. However, the raw sources of data are documented in the case study database. Examples of these sources are case study notes and the documentation that is used and referred to (also available in the bibliography at the end of this report). Recordings of all the interviews that are conducted and the full transcripts of these interviews are also in the database. The database is not included in the thesis report itself, partly due to confidentiality reasons regarding the interview recordings and transcripts.

The third data collection principle *(c)* that is followed is to maintain a chain of evidence. This principle seeks to make the line of reasoning in this research clear and visible, in order for external parties to trace back the argumentation for the presented conclusions and unravel the evidence that is the foundation of these conclusions. The steps should traceable in both directions, from the case study/research questions to the conclusions and back (Yin, 2003, pp. 105-106).

In Figure 5 the chain of evidence for this double case study is presented. The figure shows the chain of evidence from the primary (raw, unprocessed) data sources to the cross-case analysis, which is divided over four chapters and in some cases combined with findings from the literature review. For each of the steps in the chain it is specified where the information can be found (case study database, case results or cross-case analysis) and the thesis' chapter is given. The black arrows illustrate the actual 'chain'.

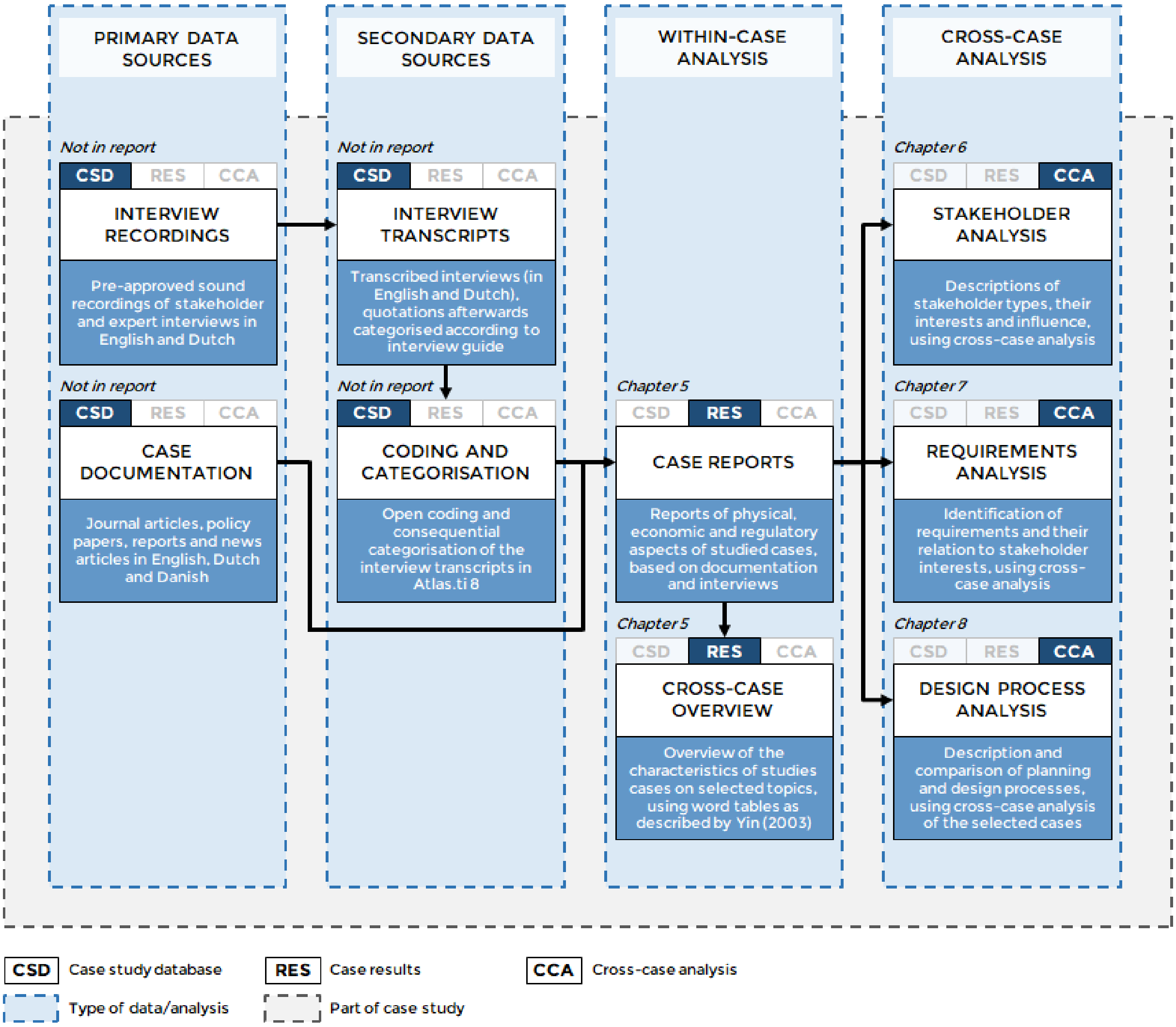


Figure 5 – Chain of evidence for the double case study on Amsterdam and Copenhagen (own illustration)

4.3. Selection of organisations and interviewees

The organisations and individuals (participants) that are interviewed need to be carefully selected. In each of the two cases both stakeholders and experts in the DH sector are interviewed. Interviews with stakeholders mainly aim to provide insight on 1) the DH system and the heat planning process and 2) the organisation, its activities and requirements towards DH and 3) the opinion of the interviewee on the influence the design of the DH system has on the sustainability of the metropolitan heat supply. The expert interviews 1) also focus on the DH system and the planning process, but from a somewhat more broad and perhaps unbiased perspective, and on 2) the opinion of the expert on the influence of the DH system design on the sustainability of the heat supply. The expert interviews are expected to be slightly more 'free' and open-ended than the stakeholder interviews, as the latter are needed to provide a more descriptive presentation of the DH system and the actors within the system. However, both interview types are semi-structured and almost entirely consist of open-ended questions.

The goal is to conduct around ten interviews per case. This considers both the case study criterion of construct validity and the constraint of a limitation in available time to conduct the research. In qualitative studies, researchers typically want to include many different perspectives and activities and therefore gain access to a wide range of individuals (Bryman, 2012, p. 416). As stated in section 4.1 the participants are selected through purposive sampling, which aims to sample participants in a strategic way to make sure they are relevant to the research question and offer sufficient variety to ensure they differ on key characteristics (Bryman, 2012, p. 418). In the cases of the DH systems of Amsterdam and Copenhagen, the interviewees need to represent the variety of roles and stakeholders that are active within the system.

Bryman drafts a list of different purposive sampling approaches. The participants for the stakeholder interviews are selected through *stratified purposive sampling*, described as sampling of typical individuals within subgroups of interest, in order to capture the variety of actors and roles by interviewing a stakeholder that is typical for that 'type' within its case. Expert interview participants are selected using *maximum variation sampling* to ensure a wide variety of expertise, opinions and perspectives on the DH system design and process (Bryman, 2012, p. 419). Both will incorporate elements of snowball sampling in the sense that some participants were recommended by other interviewees or researchers, e.g. members of the thesis committee or DTU staff (Bryman, 2012, p. 424).

COPENHAGEN							
#	ORGANISATION TYPE	ROLE(S) IN DH	OWNERSHIP	STAKEHOLDER OR EXPERT	#	FUNCTION INTERVIEWEE(S)	LOCATION
1	**District heating company**	DSO, provider	Cooperative	Stakeholder	1	Director	Taastrup
2	**Energy company**	Producer	Private	Stakeholder	2	Lead Contract Manager	Gentofte
3	**Housing association**	Consumer	Cooperative	Stakeholder	3	Head of Climate and Resources	Copenhagen
4	**Heat planner**	SSA	Public	Stakeholder	4	Chief Economist	Frederiksberg
5	**Heating transmission company**	TSO	Public	Stakeholder	5	CEO	Frederiksberg
6	**Utility company**	Producer, DSO, provider	Public	Stakeholder	6	Energy Planner	Copenhagen
7	**Municipality**	Government	Public	Stakeholder	7	Energy Planner	Roskilde
					8	Energy Planner	
8	**Engineering consultancy firm**	-	Private	Expert	9	Senior Market Manager	Copenhagen
9	**University**	-	Public	Expert	10	Emeritus Professor	Lyngby
10	**Engineering consultancy firm**	-	Private	Expert	11	Partner	Copenhagen
11	**Lobby organisation**	-	Private	Expert	12	Senior Consultant	Frederiksberg

AMSTERDAM							
#	ORGANISATION TYPE	ROLE(S) IN DH	OWNERSHIP	STAKEHOLDER OR EXPERT	#	FUNCTION INTERVIEWEE(S)	LOCATION
12	**Housing association**	Consumer	Cooperative	Stakeholder	1	Policy Advisor	Amsterdam
13	**Ministry**	Government	Public	Stakeholder	2	Program Manager	The Hague
					3	Department Manager	
14	**Ministry**	Government	Public	Stakeholder	4	Policy Officer	The Hague
15	**Municipality**	Government	Public	Stakeholder	5	Strategic Advisor	Amsterdam
16	**Energy company**	Producer, DSO, provider	Private	Stakeholder	6	Business Manager / Asset Manager	Amsterdam
17	**Waste & energy company**	Producer, DSO	Public	Stakeholder	7	Project Leader Heating	Amsterdam
18	**Waste & energy company**	Producer, DSO, provider	Public	Stakeholder	8	Manager Heating	Alkmaar
19	**Heating cooperative**	DSO, provider	Cooperative	Stakeholder	9	Chairman	Amsterdam
20	**Strategy consultancy firm**	-	Private	Expert	10	Managing Director for Energy	Utrecht
21	**Economic research agency**	-	Private	Expert	11	Methodologist & Energy Expert	Amsterdam
22	**University**	-	Public	Expert	12	Professor of Regulation of Energy Markets / Senior Researcher	Amsterdam
	Institute for applied research	-	Public	Expert			The Hague
23	**University**	-	Public	Expert	13	Post Doc Researcher	Utrecht

Table 3 – Selection of organisations and interviewees in Copenhagen and Amsterdam

These sampling approaches resulted in 23 interviews, spread over both cases. In Copenhagen eleven interviews are conducted; seven with stakeholders and four with experts. In Amsterdam twelve interviews are conducted; eight with stakeholders and four with experts. The participants and some of their properties are shown in Table 3.

4.4. Case protocol

In preparation for the actual conducting of the case studies Yin (2003, p. 67) emphasises the importance of a case study protocol, as this increases the reliability of the case study and should assist the researcher in collecting and reporting the data. Having a case study protocol is even considered essential when doing a multiple-case study. The case protocol could provide an overview of the relevant readings on the topic being investigated and of the case study objectives, describe the field procedures, should establish an interview guide with questions for the semi-structured interviews and it should give an outline for the case reports (Yin, 2003, pp. 67-69). Relevant literature and the case objectives are described in Chapter 3 and 4.

Procedures include a standardised introductory email and some rules and guidelines for the interviewer to be used before, during and after the interview. After selection of participants for the stakeholder and expert interviews they are approached via email, introducing the research to the potential interviewee and inviting him or her for an interview. The motive for the interview, the goal of the study, the researcher's background and the expected interview duration are illustrated, among other things. A standardised format for this introductory email can be found in Appendix C.

The case study is for a large part built on the semi-structured interviews. These interviews follow an interview guide that covers multiple topics and includes several open-ended questions for every topic. However, the course of the interview and the actual order of the questions that are asked is not carved in stone (Adams, 2015, pp. 496-500) and should be flexible (Bryman, 2012, pp. 471-476). Very important is the recording of the interviews for later transcription, as is nearly always done in qualitative research (Bryman, 2012, pp. 472-474). In order to be able to record the interview properly, the participant is asked to arrange a quiet and/or closable room in case the interview takes place in his/her office. There are separate interview guides for the stakeholder interviews and the expert interviews, but the same guides are used for interviews in both the cases of Copenhagen and Amsterdam, although the latter are literally translated into Dutch. These interview guides also incorporate some rules and guidelines for before, during and after the interview, to be used by the researcher. The guides are included in Appendix D.

The outline for the case reports consists of five subjects; the *historical development of the DH sector*, the *current DH system(s)*, the *regulatory framework*, *economic parameters* and *future challenges*. Some of these subjects are divided in more specific topics, although they are more or less the same for both cases. Only the subject of the regulatory framework is divided in different topics in each of the cases – as policies and regulations vary per country – although both cover the most important national and local policies and regulations. In section 5.1 the case results are described according to this structure, which is thus almost identical for both cases to ensure comparability. The cases characteristics are summarised and presented side by side in a cross-case overview in section 5.2. All activities regarding the case study, including collection and analysis of both theoretical data (from documentation) and empirical data (from interviews), are briefly summarised and presented in Table 4.

BEFORE INTERVIEW		DURING INTERVIEW		AFTER INTERVIEW	
Step	**Activity**	**Step**	**Activity**	**Step**	**Activity**
1	Collecting documentation on case. Including historical development, system characteristics, regulation and stakeholders	5	Thanking interviewee for time and introducing researcher and interviewee	9	Listening to recording and literally transcribing the interview
2	Preparing by conducting desk research on organisation and interviewee	6	Conducting semi-structured interview, asking questions while loosely following interview guide	10	Re-reading the transcription, correcting errors and structuring the text
3	Retrieving contact details, sending introductory email with explanation of research and its goals	7	Continuing on notable statements and questioning opinions and ideas	11	Coding the structured transcriptions in Atlas.ti 8
4	Setting date, time and location with interviewee and aligning expectations	8	Summarising the interview, wrapping up the conversation and thanking the interviewee again	12	Analysing the coded transcriptions and drafting case reports

Table 4 – Case study activities, in order of appearance

4.5. Data analysis

All information that is gathered is analysed and interpreted methodologically. Bryman (2012, p. 565) states that there are no clear-cut rules about how qualitative data analysis should be conducted. He describes two strategies in more detail; analytic induction and grounded theory, both of which will not be used in this research, as these methods are of an iterative nature and are quite extensive and time-consuming. Instead, a more general qualitative data analysis approach is applied.

For the analysis of (text) documents like articles and books, qualitative content analysis is a widely used research method (Hsieh & Shannon, 2005, p. 1278). Bryman also specifically mentions qualitative content analysis as an approach to the analysis of documents. Hsieh & Shannon distinguish three different approaches within the qualitative content analysis method; *conventional*, *directed* and *summative* content analysis. The case documentation for both cases is analysed using the conventional content analysis approach, as this is usually appropriate when existing theory and literature is limited and the researcher needs to let theories and categories flow from the data in an inductive fashion. For this study, this is the case.

The analysis of the semi-structured interviews does not need to differ much from the document analysis. Both are subject to qualitative data analysis. The interviews are analysed using the method of qualitative content analysis too, as the transcripts are examples of text data, although obtained through interviews instead of books or journal articles (Hsieh & Shannon, 2005, pp. 1278-1279). An unique feature of qualitative content analysis is the flexibility of using inductive or deductive approaches, or a combination of these two, according to Cho & Lee (2014, pp. 4-5). The interview analysis will indeed mix an inductive with a deductive approach, at least to a certain extent, as it will mainly employ a conventional approach, but incorporates elements of directed content analysis (Hsieh & Shannon, 2005, pp. 1281-1283). The latter focuses on validating the theoretical framework on (technical, economic, regulatory and societal) factors and roles within DH, which are derived from current literature in Chapter 3. For this, the existing theory is used in focusing the interview questions and in steering the initial coding for these topics. The other topics of the semi-structured interviews will be analysed in an inductive, 'conventional' way where codes are derived from the text and categorised in a next step (Cho & Lee, 2014, pp. 10-11) (Hsieh & Shannon, 2005, pp. 1279-1280).

Bryman provides some additional considerations on coding (interviews) in qualitative data analysis. He suggests to start coding as soon as possible to sharpen the understanding of the data, especially when data is collected through interviews. Furthermore, reading through the initial set of transcripts first without taking notes and coding is recommended, followed by the drafting of many marginal notes; the first step in (open) coding. Then codes need to be reviewed and if necessary rephased or -organised, after which relationships between codes and the (higher-order) categories they are a part of are described (Bryman, 2012, pp. 576-577). This strategy is thus applied to the analysis of the transcripts of all 23 interviews. After transcribing the interview the text is (re-) structured, as the semi-structured approach could lead to more 'messy' conversations. The reorganised text is then coded using the qualitative data analysis software *Atlas.ti 8* (ATLAS.ti Scientific Software Development GmbH, 2020). For the first interviews that are coded several initial codes and code groups are created. The number of codes and code groups grows rapidly during the processing of the first handful of interviews, after which this growth slows down and eventually stops when a certain degree of saturation is reached. During this process, initial codes and code groups are adjusted and rearranged in an iterative manner. Another step in this (open) coding procedure is indicating relationships between codes, which is also conducted iteratively. Finally, all 23 interviews are fully coded with over 150 different codes in 11 groups that range from *Challenges for DH systems* to *Regulation* and to *Financial/economical aspects*.

Lastly, *within-case analysis* of both cases is based on desk research, the coding of the transcripts in Atlas.ti 8 (ATLAS.ti Scientific Software Development GmbH, 2020) and the categorisation and relationship of the codes. This analysis is presented in a descriptive manner in two separate case reports in section 5.1, following the case report outline as discussed in section 4.4. In section 5.2 a cross-case overview is presented in the form of a word table using a uniform framework, like Yin describes the technique of cross-case synthesis (2003, pp. 133-137). Through the cross-case analysis of the case reports and the word table – which focuses on different elements of the DH systems and the planning processes – cross-case conclusions that answer sub-questions 2 and 3 can be drawn. Chapters 6, 7 and 8 go into these sub-questions and discuss these cross-case conclusions.

5

CASE RESULTS

District heating systems in Copenhagen and Amsterdam

ARC's *Amager Bakke* waste incineration plant, Copenhagen

In this chapter the results of two case studies are presented, based on analysis of the available case documentation and interview results. The cases are presented in section 5.1 in the form of two extensive case reports; one on the district heating systems of the Greater Copenhagen area and one on the district heating systems of the Greater Amsterdam area. In section 5.2 a cross-case overview of the two cases is provided, showing selected criteria.

5.1. Case reports

The two case reports each consist of five elements: the historical development of DH in the area, the current DH system, the regulatory framework, various economic parameters and the main challenges for DH in the area. The reports are mainly descriptive and are based on both publicly available documentation and the interviews that the author conducted with selected stakeholders and experts in the two areas.

5.1.1. Copenhagen

The district heating system of Greater Copenhagen is considered to be one of the largest systems in the world. It consists of many smaller DH systems that are connected to each other and have a centralised heat production. In this section the Greater Copenhagen (GC) system is described along five main subjects: the historical development, current system, regulatory framework, economic parameters and future challenges.

5.1.1.1. Historical development in Denmark and Copenhagen

Already in 1869 steam was used for the first time to heat a building in Copenhagen (CTR, 2014, p. 3). Over the years the development of DH systems in Denmark has been closely connected to the rise of CHP. The first CHP-plant in Frederiksberg, near Copenhagen, provided both electricity and heat from waste incineration to a nearby hospital as early as 1903 (Jessen, 2017, p. 3) (Danish Energy Agency, 2017, p. 11) (CTR, 2014, p. 3). The first collective DH systems were developed in the 1920’s and 1930’s to supply urban areas with waste heat from electricity production (Danish Energy Agency, 2015, p. 3). Starting with a 4% market share in the heating market, DH delivered heat to approximately 30% of all Danish homes in the 1970’s (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 13).

The international oil crisis of 1973 and 1974 marked an important change in the Danish energy sector. Given the high household energy use and Denmark’s strong dependency on imported (fossil) fuel, the crisis boosted awareness and acted as a catalyst for developments regarding fuel efficiency. This led to the decision to establish CHP-plants throughout Denmark, not only in the larger cities, but also in smaller towns and villages (Danish Energy Agency, 2017, p. 11). Before the 1970’s, many Danes still had small oil-fired boilers to heat their homes. The energy crisis and the discovery of natural gas fields in the Danish North Sea led to the first Heat Supply Act in 1979, which focused on regional heat planning by provinces/counties and municipalities. The municipalities were then required to map (future) heat demand, supply methods and energy use and to prepare options for future heat supply. Based on this the provinces then prepared regional heat plans that prioritised supply options per area and identified locations for supply units and networks (Danish Energy Agency, 2017, p. 11). Next, municipalities developed local heat plans that included ‘zoning’ of areas for either DH or natural gas networks. This was aimed at preventing overinvestments in infrastructure by identifying (urban) areas as most viable for infrastructure development (in contrast to e.g. individual oil boilers), as efficiency in energy systems was key. Developing, expanding or changing a local DH system was to be approved by local authorities, based on carefully evaluated (DH-) project proposals (Danish Energy Agency, 2017, pp. 11-12).

The first Heat Supply Act of 1979 also introduced the possibility for municipalities to impose an obligatory connection for new and existing buildings to the public DH or natural gas network. This was aimed at securing infrastructure investments in DH. This regulation is still in effect, although rarely used today. Furthermore, in 1986 an agreement between the national government and electricity utilities introduced small-scale CHP-units as a priority, combined with a test and demonstration program of different boiler/fuel types, like biomass and waste. Two years later, electric heating was prohibited in new buildings and in 1994 this was extended to existing buildings that were in a DH or natural gas area. The combination of the obligatory connection and the restrictions on electric heating ensured a stable income for DH and natural gas companies and enhanced competitiveness of these collective energy networks (Danish Energy Agency, 2017, p. 12).

Between the early 1970’s and 1990 the share of both DH and natural gas networks in the heating sector continued to grow, from 20% to 40% and from 0% to 10% respectively. After 1990 both technologies grew further and in 2017 DH supplied 65% of all Danish households with space heating and domestic hot water. Total DH supply amounted to 128 PJ in 2015, of which approximately 67% was produced in CHP-plants (Danish Energy Agency, 2017, pp. 4-5). The market share of natural gas networks has been slightly declining in the last few years, to 15.4%. Other residential heating technologies were individual oil boilers, the third largest, direct electrical heating (4.5%), individual biomass boilers (3%) and individual heat pumps (2.7%) (Lauersen, 2019).

When focusing on Greater Copenhagen, it becomes clear that DH has developed even more strongly in this densely populated metropolitan area. In the second half of the 19th and first half of the 20th century, different utility companies arose in Copenhagen and its neighbouring municipalities. Through decades of development and mergers, larger utility companies formed, carrying out activities ranging from drinking water supply, waste water treatment, distribution of town gas and district heating production/distribution, but which were still focused on one municipality. This changed in the last quarter of the 20th century, when the report *"Power and heat transmission in Greater Copenhagen"* was published, which concluded a DH transmission grid for the Greater Copenhagen area was financially feasible (CTR, 2014, p. 3).

After the Heat Supply Act of 1979 assigned municipalities with the task to form a municipal heat plan, the first *"Heat Plan of Copenhagen"* was passed and adopted by the municipal council in 1984. This plan led to an obligatory connection for households in the designated DH areas, resulting in strong growth for the DH system. Besides the construction of two new CHP-plants, two transmission companies were founded in 1984, CTR and VEKS, both owned by several municipalities (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 17) (CTR, 2014, p. 3). A very large heat transmission system was developed, connecting several different (local) distribution systems and creating better conditions for new DH systems in other municipalities. Before, a range of small to medium sized plants were each supplying to a separate distribution network and three larger power plants on the island of Amager were not utilized optimally in terms of potential heat capacity. By connecting the different DH networks with each other and several larger CHP-plants, the transmission network was able to optimise the total system (DBDH, 2020). This resulted in a 80% market share for DH in 1995 and ultimately in the 98% share that can be seen today (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, pp. 17-18).

5.1.1.2. Current DH system of Greater Copenhagen

The Greater Copenhagen DH system is, by far, the largest system in Denmark and one of the largest in the world. With a population of around one million, spread over more than 20 municipalities, and a population density of 4,400/km^2 in the City of Copenhagen and 1,200/km^2 in the Copenhagen metropolitan area, the region is heavily populated. Per year, the DH system supplies approximately 35 PJ of heat to the consumers that are connected to one of the distribution systems that are connected via transmission pipes. The system spreads out over 50 kilometre from the Eastern to the Western part of the system (Danish Energy Agency, 2015, p. 5). Together, the six largest DH systems in Denmark distribute a total heat production of 67 PJ per year, The Copenhagen system thus supplies more heat than the next five largest systems combined. Besides these, there are around 400 smaller, decentralised DH systems in less densely populated areas of Denmark, that together cover around 53 PJ of heat production annually (Danish Energy Agency, 2017, pp. 4-5).

In the Greater Copenhagen system the transmission network has a pipe length of around 180 km, for both a forward and a return pipe (Rambøll, 2012) (Rambøll, 2020). The different distribution systems collectively have a (double) pipe length of 1,500 km (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, pp. 16-17). This entire interconnected system supplies heat to approximately 500,000 end users, equivalent to a rough one million people. When looking at the system different physical elements can be distinguished. Several stakeholders are involved, each with varying roles and responsibilities. These will all be briefly described below, divided in four groups with (main) activities: *production*, *transmission*, *distribution* & *consumption*.

Production

Given the scale of the Greater Copenhagen DH system and the high collective heat demand, it is obvious that this demand cannot be met by one single production facility alone. Therefore, there is a wide variety of facilities for heat production spread out over the metropolitan area, as can be seen on Figure 6, on page 53. There are a handful of large scale base load production facilities, mainly CHP-plants and waste incinerators. Furthermore, there are many more peak load plants, although these are often much smaller and in some cases rarely used.

When zooming in on these production plants, we can distinguish between large CHP-plants for base load, waste incineration and wastewater treatment plants and other facilities. The first group, consisting of only four CHP-plants, produces approximately 70% of the yearly heat supply in the Greater Copenhagen (GC) system, as can be seen in Table 5 on the next page. Two of these plants, *Avedøreværket* and *H.C. Ørstedværket*, each with a heat capacity of more than 800 MWth, are owned and operated by Ørsted, a Danish multinational energy company that is mainly active in power production. Ørsted is traded on Nasdaq Copenhagen and can be considered a commercial, profit-seeking company, but is owned for 50.1% by the Danish state.

Another CHP-plant, *Amagerværket*, with a thermal capacity of 650 MWth, is owned by HOFOR. HOFOR has around 1 million customers in the Greater Copenhagen area and is active in water, wastewater, district heating and cooling, town gas and (renewable) energy production (HOFOR, 2018). In its core areas HOFOR is Denmark's largest utility company. The utility is active in water and wastewater in eight different municipalities in GC that together are the

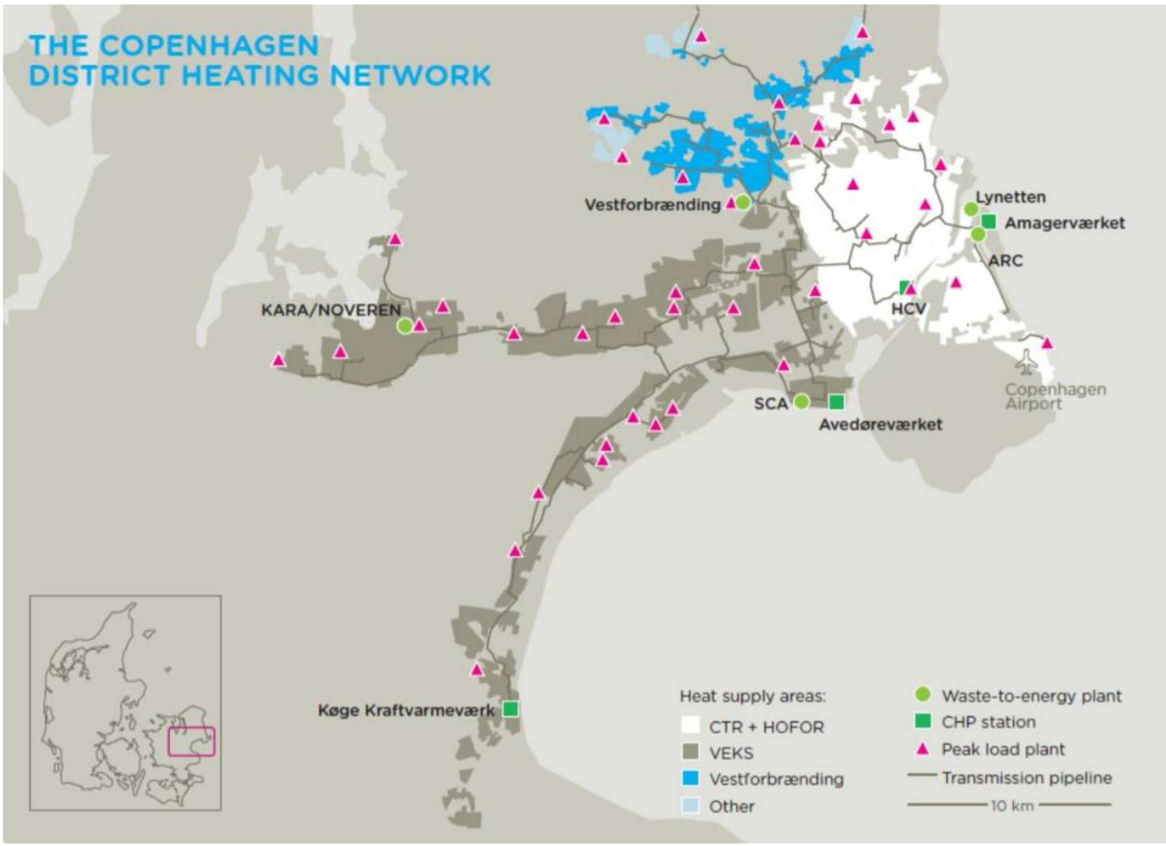


Figure 6 – The Greater Copenhagen DH system, with the catchment areas of the main transmission and distribution companies and (most of) the base load and peak load plants (Overbye, 2019)

municipal owners of HOFOR. HOFOR's activities in town gas and district heating and cooling are limited to the municipality of Copenhagen. Besides its activities as a utility in several fields, HOFOR acquired the *Amagerværket* CHP-plant from Vattenfall in 2013. This coal- and biomass-fired power plant is converted by HOFOR to a 100% biomass plant in 2020. The fourth CHP-plant for base load is much smaller, with only 81 MWth of capacity. This *Køge Kraftvarmeværk* plant is owned by VEKS, which is one of the two large and interconnected transmission system operators in GC. VEKS is, like HOFOR, co-owned by several municipalities in the metropolitan area, twelve in this case. The heat produced by this plant is partly delivered to VEKS' own transmission system and partly to the new greenfield DH system in the town of Køge (VEKS, 2019).

% OF TOTAL SUPPLY	TYPE	PRODUCTION FACILITY	RESOURCE	CAPACITY (HEAT)	COMPANY	OWNERSHIP
70%	CHP	Avedøreværket	[a] Coal and biomass	856 MWth	Ørsted	[1] Traded on Copenhagen Stock Exchange
		HC Ørstedværket	[b] Natural gas	815 MWth	Ørsted	[1] Traded on Copenhagen Stock Exchange
		Amagerværket	[c] Coal and biomass	650 MWth	HOFOR	[2] Owned by 8 municipalities
		Køge Kraftvarmeværk	[d] Biomass	81 MWth	VEKS	[3] Owned by 12 municipalities
25%	Waste incineration	Amager Bakke	[e] Waste (solid)	247 MWth	ARC	[4] Owned by 5 municipalities
		Energitårnet	Waste (solid)	100 MWth	ARGO	[5] Owned by 9 municipalities
		Vestforbrænding i Ejby	Waste (solid)	204 MWth	Vestforbrænding	[6] Owned by 19 municipalities
	Wastewater treatment	Lynetten	Waste (water, sludge)	[A] Unknown	BIOFOS	[7] Owned by 15 municipalities, via other utilities like HOFOR or Glostrup Forsyning
		Avedøre	Waste (water, sludge)	[A] Unknown	BIOFOS	[7] Owned by 15 municipalities, via other utilities like HOFOR or Glostrup Forsyning
5%	Other	Pectin factory in Køge	Excess heat (industrial)	5 MWth	CP Kelco	Subsidiary of very large family-owned company (*J.M. Huber Corporation*), based in United States
		Geothermal plant near Amagerværket	Geothermal energy	[B] 14 MWth	HGS	*Hovedstadsområdets Geotermiske Samarbejde*: cooperation between CTR, VEKS & HOFOR
		Several (appr. 30) CHP-plants and heat-only boilers for peak load	Varies; natural gas, coal, fuel oil, biomass	Varies: from >100 MWth to <5 MWth	Varies; CTR, Ørsted and distribution companies	Varies; (combined) municipal ownership, private ownership, cooperative ownership (via distribution system operators)

Table 5 – Production facilities for the heat supply in the Greater Copenhagen DH system

The second group consists of waste incineration and wastewater treatment plants and cover approximately 25% of the GC system's annual heat demand. Three waste incinerators deliver their heat to the GC system, although one of these three also owns and operates its own DH system and only delivers surplus heat to the integrated system in the metropolitan area. This waste company, called *Vestforbrænding*, is Denmark's largest waste management, recycling and energy company. It is owned by 19 regional municipalities for which it handles household and commercial waste, to be recycled or incinerated. Besides its activities in waste management, Vestforbrænding also owns an incineration plant with 204 MWth of heat producing capacity and a DH distribution system that delivers heat to consumers in five different municipalities north-west of Copenhagen (Vestforbrænding, 2019). The other two waste incinerators, *Amager Bakke* of the company ARC and *Energitårnet* (Energy Tower) of ARGO are both owned by a group of municipalities, 5 and 9 respectively. These municipal companies are responsible for waste management in their owner municipalities and produce electricity and heat in their waste incinerators (ARC, 2020) (ARGO, 2020). The heat produced by these plants is delivered to the GC system.

Also in the second group, thus together with the waste incinerators covering 25% of the GC system's total heat supply, are two wastewater treatment plants owned by BIOFOS. Like many stakeholders in the system, BIOFOS is municipally owned by 15 different towns and cities, for which it handles wastewater of a combined 1.2 million inhabitants. The collected wastewater is treated in three plants, that produce electricity, biogas and heat. Two of the plants produce heat for the GC DH system; *Lynetten* and *Avedøre* (BIOFOS, 2020).

The last group of production facilities consists of a wide range of peak load plants. This varies from Svanemølleværket, a large former CHP-plant that now only produces heat for peak load with a capacity of 270 MWth, to for example a heat-only peak load boiler in the city of Frederiksberg, which runs on gas-oil and is owned by the local DH distribution company (Frederiksberg Forsyning, 2020). Many of the peak load plants, which are spread around the metropolitan area, are older CHP-plants or heat only boilers that were used by the local DH company in different municipalities before these local distribution systems were connected via the transport network of CTR and VEKS in the 80's and 90's. Within the service area of CTR, the majority of these plants are owned and operated by CTR, where in the VEKS-area these are usually owned by the local distribution companies (Folke, 2019). However it is Varmelast, a cooperation between CTR, VEKS and HOFOR, that is responsible for the daily dispatch of heat production and thus decides which (peak load) plants will run and which will not (Varmelast, 2020). Also worth mentioning are two other production facilities in this group. One is an industrial excess heat producer, where a private company with a pectin-factory supplies heat to VEKS. This is not a large share of total heat production in GC, but still large enough to covers around 50% of the het demand in the DH network in the town of Køge (VEKS, 2020, p. 10). Another remarkable producer is HGS, a collaboration between CTR, VEKS and HOFOR, with a small geothermal (test) plant. This plant does not function well though, which made HGS return (part of) their exclusive right to utilise geothermal energy to the Danish Energy Agency, making way for private operators to hand in applications (VEKS, 2020, p. 12) (CTR, 2019, p. 8).

Notable is the fact that some of the stakeholders mentioned above are active solely in the role of producer within the GC system. Ørsted would be an example, as they own two of the large CHP-plants and provide the majority of the base load for the GC DH system, but they are not involved in other activities like transmission, distribution or as heat provider/retailer. However, some stakeholders fulfil more than one role. For example; HOFOR and Vestforbrænding have (CHP-) production plants, but also own and operate large distribution systems and are active as heat providers to final consumers within those systems. VEKS is one of the two large transmission system operators in the GC system, but they also own and operate a (relatively) small CHP-plant and produce heat that's fed into the transport network. Furthermore, many of the peak load plants are owned and operated by the local distribution companies. These parties therefore perform activities in (peak load) production, distribution and delivery of heat to end-users.

Transmission

As can be seen in Figure 6 the DH system in the metropolitan area of Greater Copenhagen is divided in three major areas. In each of these areas there is one transmission system operator (TSO) that transports hot water from production plants, throughout the TSO's area, to the different distribution systems that are connected to the transport network. CTR and VEKS, both established in 1984, each own and operate their own transmission network, though these are connected and are able to transport heat to and from each other.

CTR is responsible for heat transport within the city of Copenhagen and four directly neighbouring municipalities, as is shown in Figure 7. CTR is also jointly owned by these five municipalities; Copenhagen, Frederiksberg, Gentofte, Gladsaxe and Tårnby. In each of these municipalities a separate distribution company is active, although two of these share a common municipal service company, responsible for delivery and billing to consumers (Gentofte Gladsaxe Fjernvarme, 2020). For Copenhagen, there is the company of HOFOR. Worth mentioning is the old steam system that HOFOR operates in parts of the centre of Copenhagen, although they are replacing this system for a new high temperature water-based DH system, to be finished in 2021 and currently already much smaller than in Figure 7 (Folke, 2019) (Honoré, 2019). Within this steam area, CTR does not have any transmission lines (CTR, 2014, p. 8). CTR owns and operates 54 km of transmission pipes, 31 heat-exchangers (sub-stations where heat is transferred to the distribution systems), 3 large pumping stations and 14 peak load plants and transports heat with a temperature between 70°C and 120°C to around 250,000 households (CTR, 2014, pp. 11-12) (CTR, 2019, p. 11) (CTR, 2020, p. 3).

Figure 7 – The transmission system of CTR, spread over the five municipalities it supplies to (CTR, 2014)

Just like CTR, the company of VEKS is responsible for heat transport between production plants and multiple distribution systems in different towns and cities. VEKS operates a transmission network of 132 km, with 62 heat-exchangers and 18 pumping stations, transporting heat to 170,000 households within 12 municipalities (VEKS, 2020, p. 7). Peak load plants in the VEKS-area are mostly owned by the local distribution companies, although VEKS is in charge of their utilisation (Folke, 2019). VEKS is jointly owned by these 12 municipalities; Albertslund, Brøndby, Glostrup, Greve, Hvidovre, Høje-Taastrup, Ishøj, Køge, Roskilde, Rødovre, Solrød & Vallensbæk. VEKS is also involved in a new DH development in the town of Køge, where it established and exploits a distribution grid for 5,500 households (Køge Fjernvarme, 2020). This makes VEKS differ significantly from CTR, as CTR is only active in the role of TSO, where VEKS participates in various activities, ranging from heat (and even electricity) production in the Køge Kraftvarmeværk CHP-plant, to transmission, to distribution and delivery to end-users through their participation in distribution company *Køge Fjernvarme*.

As can also be seen in Figure 6 there is a third, smaller transmission system in the Greater Copenhagen area. Vestforbrænding, established in 1970, is the largest waste management company in Denmark and operates a large waste incineration plant in Ejby, as is already shown in Table 5. In the decades after 1970, Vestforbrænding developed and expanded its own DH system, fed with heat from their CHP incineration plant. The company is owned by 19 municipalities, for which it handles household and commercial waste; Albertslund, Ballerup, Brøndby, Egedal, Frederiksberg, Furesø, Gentofte, Gladsaxe, Glostrup, Gribskov, Halsnaes, Herlev, Hillerød, Høje-Taastrup, Ishøj, København, Lyngby-Taarbæk, Rødovre & Vallensbæk (Vestforbrænding, 2020). Only in a few of those municipalities Vestforbrænding also provides DH; Ballerup, Furesø, Gladsaxe, Herlev & Lyngby-Taarbæk (Artogis, 2020). In doing this, Vestforbrænding is active in production, transmission, distribution and providing of heat.

The third transmission network of Vestforbrænding is more or less separate from the networks of CTR and VEKS. The Vestforbrænding incineration plant does deliver heat to the interconnected system of CTR and VEKS, but only after the heat demand of consumers in the municipalities Vestforbrænding itself delivers to are covered. Although the two systems of CTR and VEKS are owned and operated separately, they are physically connected. Moreover, since 2008 there even is an organisation responsible for central heat planning in the transmission systems of CTR and VEKS and the connected distribution systems of 17 municipalities – the 17 owner municipalities of CTR, VEKS and HOFOR. This organisation, Varmelast, is responsible for the daily dispatch of heat production in the production facilities, as mentioned earlier. Varmelast is a cooperation between CTR, VEKS and HOFOR, established to economically optimise the heat supply in their DH areas and to ensure the lowest possible costs for its consumers (CTR, 2014, p. 8). Varmelast has also been established because the power producers that owned the CHP-plants in the GC system were privatised and therefore could not be responsible for optimising heat production anymore (Folke, 2019). This was due to the fact that they were going to be each other's competitors on the liberalised power market and therefore had to prevent the competition of getting access to knowledge on their production business (CTR, 2014, p. 8). Varmelast was thus created to have a (somewhat) independent and heavily regulated party responsible for heat load dispatch.

Varmelast bases the central heat planning on daily heat demand forecasts by CTR, VEKS and HOFOR and the reported operational capacity for that day by the producers in the system and their offers. Each day, Varmelast calculates the economically optimal distribution of production among these facilities, also taking into account bottlenecks in the transmission network (Varmelast, 2020). The production companies base their offers on factors like fuel prices, possible revenue on the electricity market (in case of CHP-plants), taxes (on CO_2 and energy), subsidies (e.g. for biomass-based electricity production), emission costs and maintenance costs (Varmelast, 2020). For most hours of the year supply by CHP-plants is cheaper than by the smaller (heat-only) peak load plants, except for hours with a very low electricity price. Furthermore, as most CHP-plants are fuelled by biomass and this share is still increasing, the CHP-plants benefit from subsidy for biomass-based electricity production, exemption from energy- and CO_2-taxes and the fact they don't need CO_2 credits. The heat plan that Varmelast prepares in collaboration with the heat producers is finalised around 10:30 AM on the day before the heat plan is implemented. During the day itself, the heat plan is adjusted, based on updated demand forecasts, electricity market price developments and unexpected disruptions in production (Varmelast, 2020).

Distribution

As mentioned before there are many different DH distribution companies in the Greater Copenhagen metropolitan area. The majority of these companies, around 20 in total, is municipally owned. The other part is cooperatively owned, thus owned by its DH-consumers. Most of these distribution companies are relatively small in scale, compared to the large transmission companies of CTR and VEKS. However, a company like HOFOR, the distribution company in the city of Copenhagen and largest in Denmark, can be called quite big, given its 1,500 km network and over 250,000 connections, covering 562,000 inhabitants of Copenhagen or 98% of the city's annual heat demand (HOFOR, 2016, p. 14). Within the GC system, 17 municipalities are coupled to the interconnected system of CTR and VEKS – 5 and 12 municipalities respectively – for which Varmelast organises the heat planning. Another 5 municipalities are connected to the Vestforbrænding transmission system, although these are not integrated in the larger CTR and VEKS network and do not participate in the Varmelast collaboration. When mentioning the GC DH system in this report, from now on this will refer to the transmission and distribution systems in the Varmelast collaboration between CTR, VEKS and HOFOR, covering 17 municipalities and over 20 distribution systems. These 17 municipalities significantly vary in size and density and together they have a population of almost 1.4 million, of which almost half is covered by Copenhagen. Figure 8 below shows the population density of each municipality, Figure 53 in Appendix E shows the relative population size of the municipalities, compared to the total GC area (Statistics Denmark, 2020).

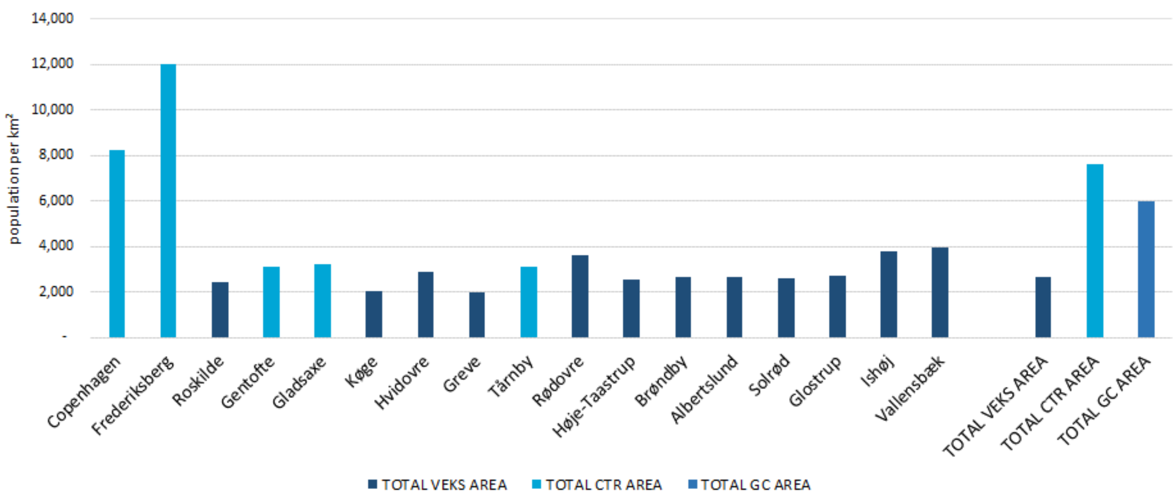


Figure 8 – Population density of all 17 municipalities in CTR and VEKS district heating area

What is easily noticed is the much larger population density of the CTR area; almost three times as densely populated as the VEKS area. However, of the five municipalities that connect to CTR's network, only two have densities that stand out; Copenhagen and Frederiksberg. As these also are the largest of the municipalities – especially Copenhagen – this does weigh heavily on the average density in CTR's area. Added that CTR's transmission system has a roughly circular shape and VEKS' network is more or less linear, the CTR network is more densely populated and more efficient in terms of population per km[1] of transmission pipe. This corresponds to the fact that CTR provides around 18 PJ annually through its 54 km[1] of transmission lines, where VEKS provides only 9 PJ with 132 km[1] (VEKS, 2020, pp. 7-9). Furthermore, the market share of DH compared to other heating technologies is higher in the five municipalities in CTR's catchment area than in the twelve municipalities where VEKS delivers DH. For example, in Copenhagen and Frederiksberg the market share of DH is 98% and 99% respectively (HOFOR, 2016, p. 14) (Frederiksberg Forsyning, 2020).

The five distribution companies that are connected to the CTR transmission system all pay the same heat price to CTR, as heat costs, including both production and transmission costs, are socialised between the different distribution companies (CTR, 2014, p. 6). However, the price these five companies charge their end-users may differ, as the distribution systems have different physical characteristics and economic efficiency (Holm, 2019). All distribution companies in the CTR-area are owned by the municipality they offer DH in; HOFOR, Frederiksberg Forsyning, Gentofte Fjernvarme, Gladsaxe Fjernvarme & Tårnby Forsyning (HOFOR, 2018, p. 4) (Frederiksberg Forsyning, 2020) (Gentofte Gladsaxe Fjernvarme, 2020) (Tårnby Forsyning, 2020). The distribution companies are responsible for bringing the thermal energy from heat-exchangers – the sub-stations that couple transmission and distribution systems – via their distribution networks to the end-users. The heat exchangers, 27 within the CTR-network, are owned and operated by the transmission companies. In the CTR-network, the same goes for most of the peak load plants. The distribution companies also offer services and billing to their consumers. The annual heat supply by CTR differs significantly between the five municipalities; for the city of Copenhagen CTR yearly covers a demand of 12 PJ (another share of Copenhagen's demand is directly covered by HOFOR), equivalent to 67% of CTR's total heat sales, where the city of Frederiksberg only needs around 2.7 PJ or 15%. Gentofte, with a demand of 1.8 PJ, Gladsaxe with 0.8 PJ and Tårnby with 0.6 PJ are even smaller (CTR, 2019, p. 15). This can be explained by the significant differences in population size of these municipalities, as becomes clear from Figure 53. The share of CTR's total heat sales that each municipality consumes does more or less correspond to this variation in size, as is also shown in Figure 9. The fact that the percentages per municipalities are not exactly equal depends on factors like the average heat demand per household and the market share of DH in a given municipality. This will be discussed later in this section (see Figure 11).

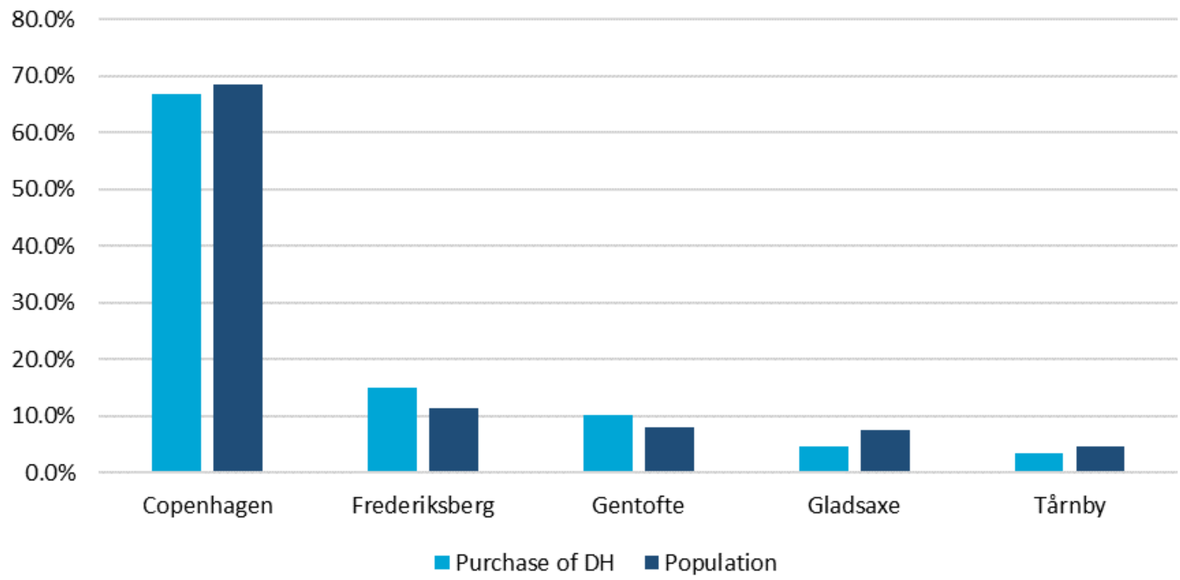


Figure 9 – Per municipality both the % of total DH sales by CTR and the % of total population of the five CTR-municipalities combined are shown (own illustration)

In the VEKS area there are 19 different local DH distribution companies, spread over the 12 municipalities that VEKS is owned by and delivers to (VEKS, 2020, pp. 7-9). This is due to the fact that in some municipalities there is more than one local DH company. The municipality of Roskilde is an example; there is a municipally-owned DH company in the city of Roskilde, called FORS (formerly Roskilde Forsyning) and a cooperatively-owned DH company in the small town of Svogerslev, called Svogerslev Fjernvarme a.m.b.a. Both are in the same municipality; Roskilde. The distribution companies in the VEKS-network are on average smaller than the five companies in the CTR-network. The VEKS-area is less densely populated and consists of smaller towns and cities, compared to Copenhagen and its direct neighbours,

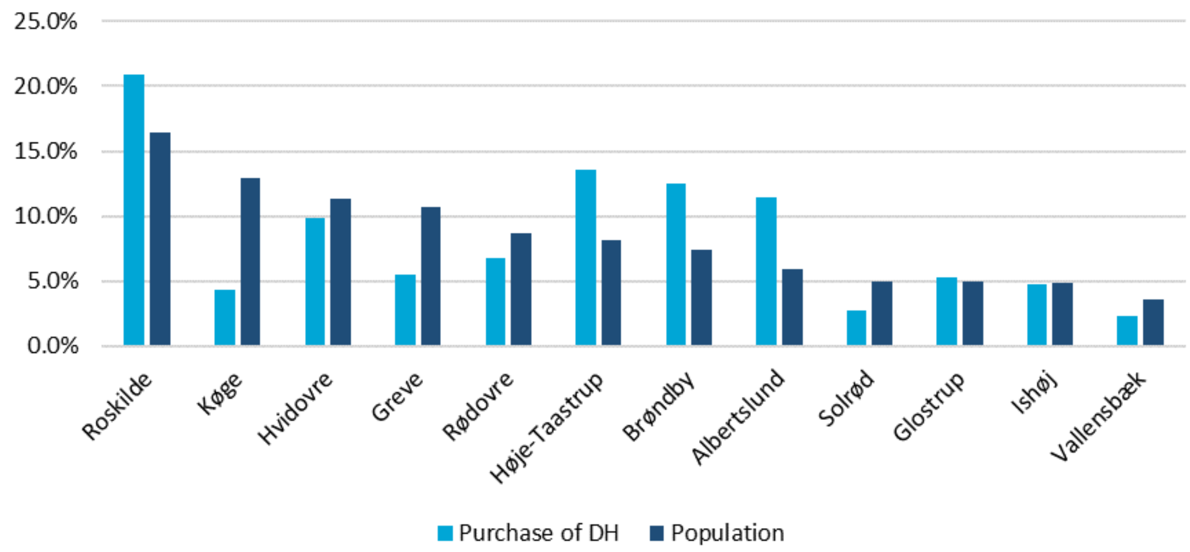


Figure 10 – Per municipality both the % of total DH sales by VEKS and the % of total population of the twelve VEKS-municipalities combined are shown

hence the small companies. A handful of these are owned by their consumers, the others are municipally owned. As said before, the heat-exchangers and pumping stations in the VEKS-network area owned and operated by VEKS. But, in contrast to CTR, most of the peak-load plants within the VEKS-area are owned by the local distribution companies (Folke, 2019). When looking at the annual heat demand in the 12 municipalities that is covered by DH, there are big differences; a city like Roskilde covers around 20% of the rough 9 PJ VEKS transports yearly, where towns like Vallensbæk and Solrød only consume between 2% and 3% (VEKS, 2020, pp. 8-9). This does not necessarily correspond to the population size of the municipality, as can be seen in Figure 10. This could be influenced by a higher share of non-residential buildings that is connected to DH in some municipalities (see under *Consumption* below), but is mainly caused by the different market share that DH has in every municipality, as can be seen in Figure 11.

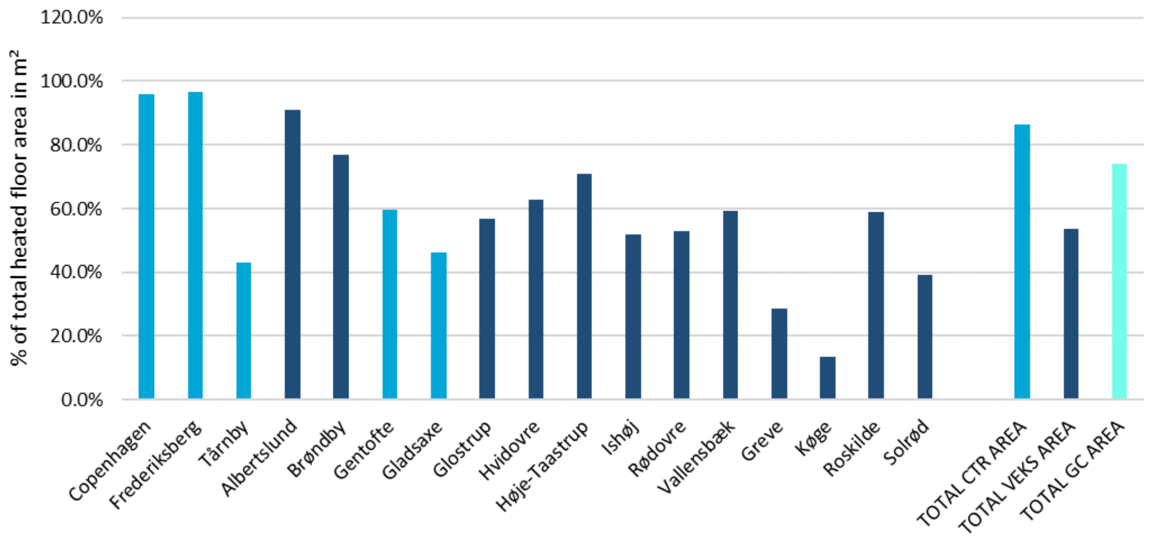


Figure 11 – Market share of DH compared to other heating technologies, based on total heated floor area

Lastly, worth noting is the thermal energy storage facility that one of the distribution companies is constructing. The company of Høje Taastrup Fjernvarme (HTF), the largest cooperatively owned DH company in Denmark, is establishing a 70,000 m³ storage pit, together with VEKS (VEKS, 2020, p. 18). This Pit Thermal Energy Storage (PTES) is basically a small and shallow lake, covered with thermal insulation. As it is a development project it received around 13 million DKK of subsidies (VEKS, 2020, p. 18). The project is co-financed by the large CHP and waste incineration producers like Ørsted and ARGO, as they expect to benefit from the possibility to store heat when there is a low or insufficient heat demand, but they still want to produce when electricity prices are high. This way the co-produced heat could be stored and used later, when heat prices are up again (Birnbaum, 2019).

Consumption

End-users or consumers come in different forms and sizes. These differences depend on a variety of things, e.g. the type of building a consumer is heating with DH, if it is a residential or non-residential building, the average energy use of that building type in GJ/m², whether someone in a residential building is a tenant or a homeowner, how a consumer is able to exert influence on the local DH company, etcetera. To provide some insight on consumers in the GC area, these characteristics are further explored.

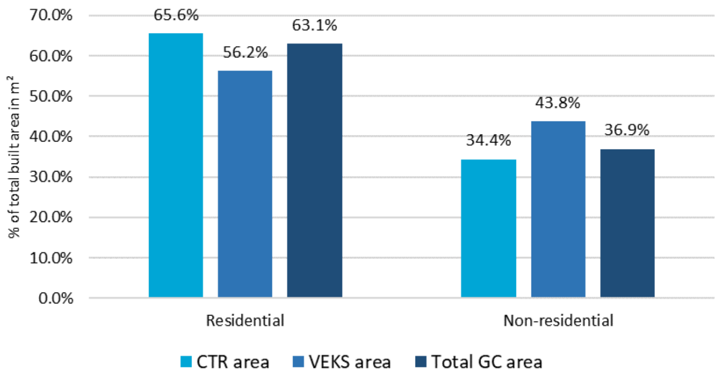


Figure 12 – Share of residential and non-residential buildings that are connected to DH in GC area

The majority of buildings – in terms of m² of heated floor space – that is connected to the GC DH system is for residential use. A rough 63% of all buildings connected to DH is residential, although there are quite some differences between areas and municipalities (Statistics Denmark, 2020). In the CTR area there is a slightly larger share of residential buildings connected to DH than in the VEKS-network, as can be seen in Figure 12. Between municipalities, this can differ even more, as for example Frederiksberg and Tårnby show. Both municipalities are within the CTR area, but in Frederiksberg almost 79% of all buildings connected to DH is residential, where this is only a bit over 47% in Tårnby (see Figure 55 and Figure 58 in Appendix E). Within the VEKS area, differences can be even larger, as is shown by Solrød with 80.1% residential DH and Glostrup, with 41.3% residential DH.

When looking at these two main categories, there are a few building types that stand out, both in the residential and non-residential category. In the entire GC area almost half of all floor area that is heated through DH is in so-called *multi-dwelling houses*; apartment buildings and housing blocks, often stacked buildings with a relatively high population density. As can be seen in Figure 13, the second largest residential building type is *detached houses* with only 5.9% of floor space and the third largest is the group with *terraced, linked or semi-detached houses*, representing 5.7%. The dominance of multi-dwelling houses is not surprising, given the higher population and heat demand density of this building type, compared to many other residential building types and the fact that the GC and especially CTR area are densely populated. The share of multi-dwelling houses is positively correlated with the population density of a municipality, as is again shown by Frederiksberg and Tårnby: 73% of all buildings (including non-residential) in

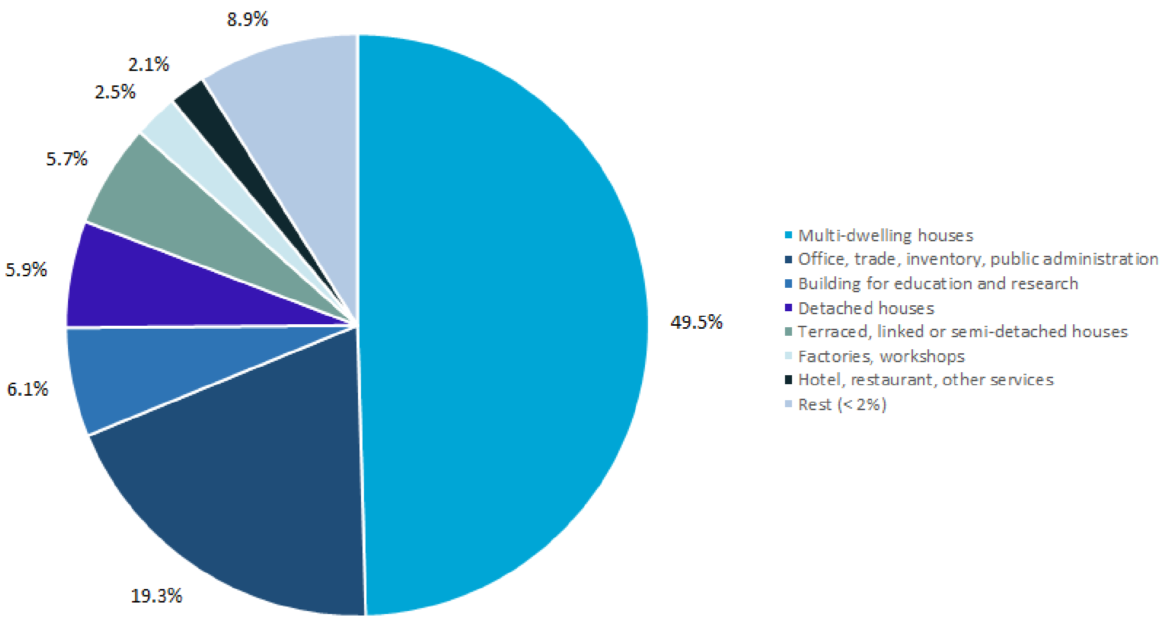


Figure 13 – Share of total floor area (m²) heated by DH, per building type, in the 17 municipalities in the GC area

Frederiksberg is a multi-dwelling house, the population density is almost 12,000/km². In Tårnby multi-dwelling houses cover 45% of all floor area and population density is just over 3,000/km². High population density and heat demand density are valuable preconditions for a DH network, making multi-dwelling houses a common and very suitable building type to be connected to DH. This can also be seen in the heat planning process in all of Denmark since the Heat Supply Act of 1979; DH was mainly for areas with relatively large buildings, natural gas grids for areas with one family houses (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 13).

Focusing at the non-residential types, the same can be said about office buildings, not surprisingly the second largest building type in all of the GC DH system. Together with educational and research buildings, which are usually relatively well comparable to office buildings, these two groups roughly represent a quarter of all floor space heated by DH in GC. The heat demand density in these types, which are often multi-story buildings and frequently lie in populated areas, is also relatively high and therefore suitable for DH. The multi-dwelling house represents the largest group of buildings connected to DH in GC. However, there can be significant differences between municipalities on what kind of buildings are connected to the local DH system. For example when looking at Copenhagen (largest municipality), Frederiksberg (most densely populated municipality and with highest DH market share) and Albertslund (smaller, less densely populated and on other transmission system) in Figure 14, it is clear there is a large variety in what kind of buildings dominate the local DH system.

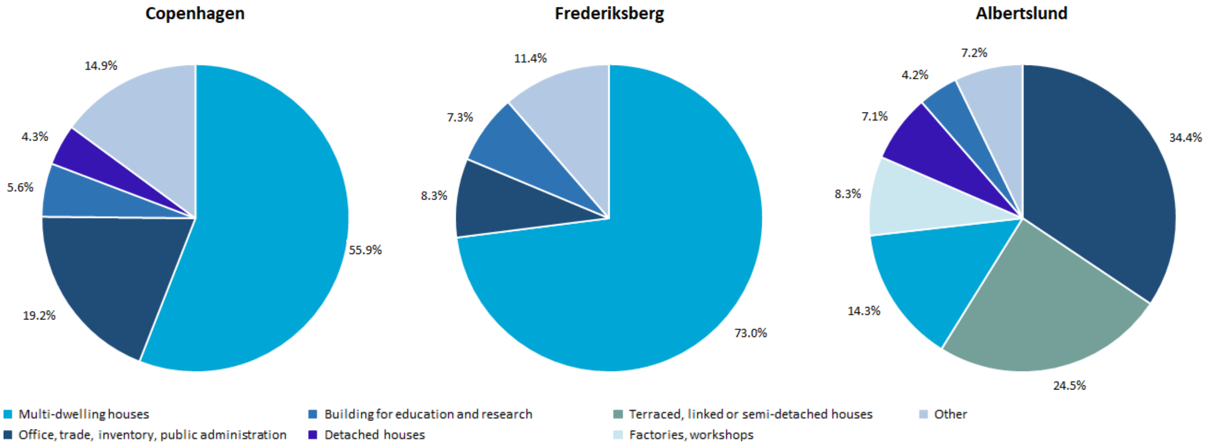


Figure 14 – Share of total floor area (m²) heated by DH, per building type for Copenhagen, Frederiksberg and Albertslund

Non-residential buildings often have way less end-users of DH per m² than residential buildings. For example; an office building of 1,000 m² possibly has only one end-user, like an insurance company or municipal government. Furthermore, for most non-residential buildings there is only one contract for DH with the local distribution company, even if there are multiple (commercial) tenants. For multi-dwelling buildings, this often is the same, as there usually is a housing association or homeowners association that is the contracting party, although there are many dwellings/households in the building and therefore numerous different entities that are represented by these associations. As the residential building category in the GC area is also the largest in terms of floor space connected to DH, it can be interesting to zoom in on this category a little further. After looking at different building types, we can focus on what 'kind' of people occupy these buildings; homeowners or tenants. Whether someone owns or rents the house he or she occupies defines what influence he or she has on the choice for DH or another heating technology (provided there is a choice, so no obligation to connect) and how he or she can exert influence on the DH companies. Owners do this either directly or through a homeowners association, tenants either through their landlord or through a housing association.

Around 70% of the residents in the area that CTR covers are tenants and around 30% own the house they live in. These percentages are significantly different in the VEKS area and in Denmark as a whole, where over 55% of the residents own their own house and around 43% is a tenant, as can be seen in Figure 15. The twelve municipalities that VEKS supplies to are – taken together – a better representation of the national average. The question is: what makes the CTR area so different? The answer could probably be found in the share of multi-dwelling houses in each of these areas. When looking at the CTR area in Figure 16 and Figure 17 it is easy to see a correlation between the share of multi-dwelling houses and the share of tenants. Multi-dwelling houses are much more often occupied by tenants than by homeowners; in Copenhagen 85.2% of dwellings in multi-dwelling houses was occupied by tenants, in Denmark this was even 87.1% and for the five CTR-municipalities this was 83.2% (Statistics Denmark, 2020).

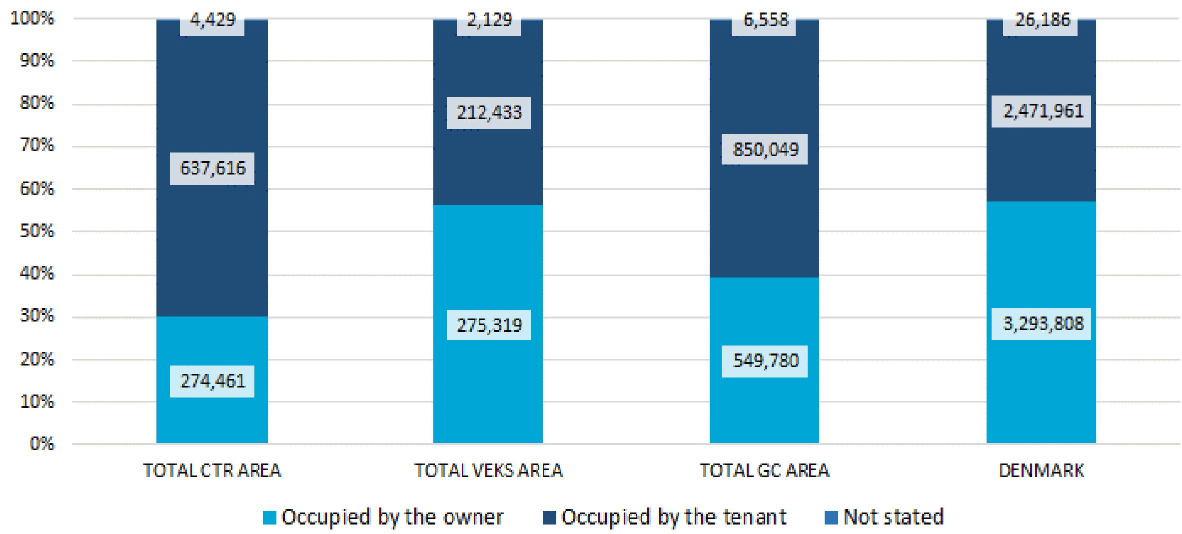


Figure 15 – Total number and percentage of tenants and homeowners in CTR, VEKS and GC area and in all of Denmark

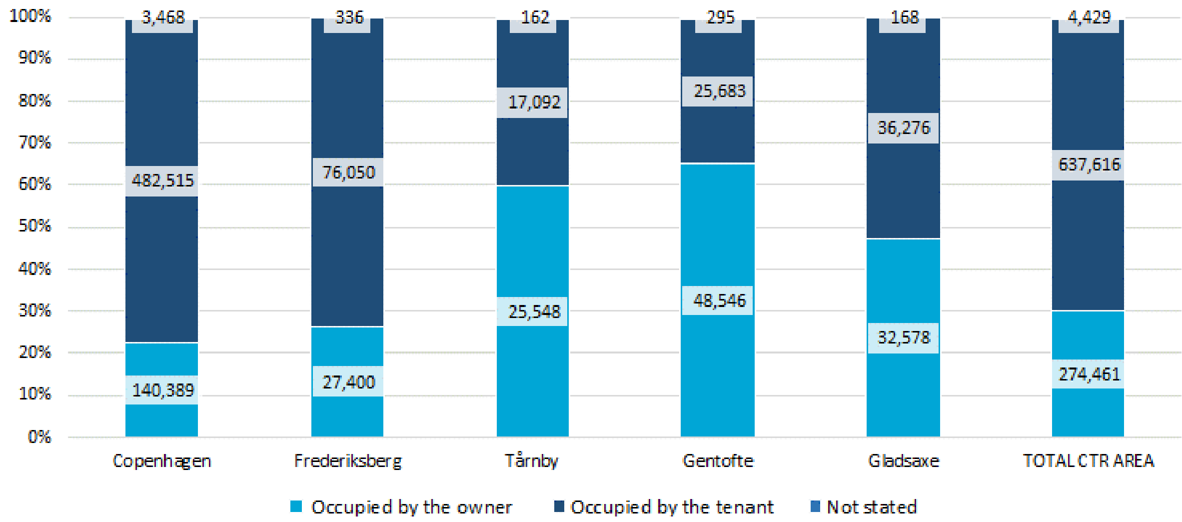


Figure 16 – Total number and percentage of tenants and homeowners in CTR area

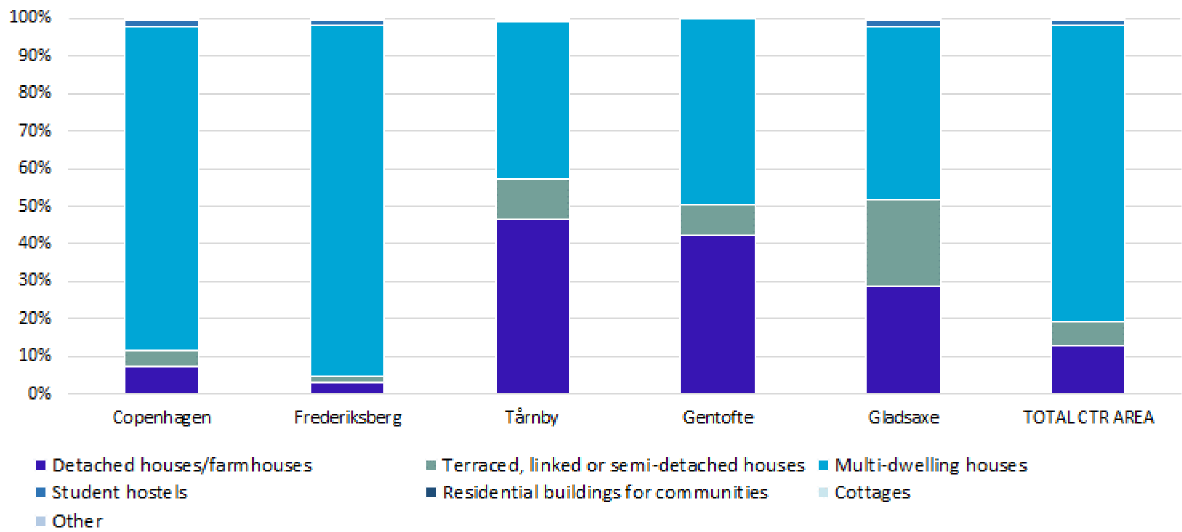


Figure 17 – Percentage of residents per dwelling type in the five municipalities of the CTR area

As said, in most cases residents of multi-dwelling houses have influence on their local DH company either through a housing association (in case of tenants) or a homeowner association (in case of homeowners). When we look at the ownership structure of multi-dwelling houses in the CTR area in Figure 18, we see that over 50% of the residents lives in an apartment that is owned by either a non-profit building society/housing association, or by a housing society, which generally is a cooperative that lets its houses to tenants and is governed by elected representatives (SAB, 2020). Where on a national level around 65% of all residents live in a privately owned house and less than a quarter in a house that is owned by a housing association or cooperative housing society, in the CTR area these numbers are very different. Especially in Copenhagen, with a 98% total market share for DH and 56% of all DH floor area in multi-dwelling houses, this makes organisations like housing associations (HA) and non-profit building societies an important stakeholder in the local DH systems, as they represent so many residents.

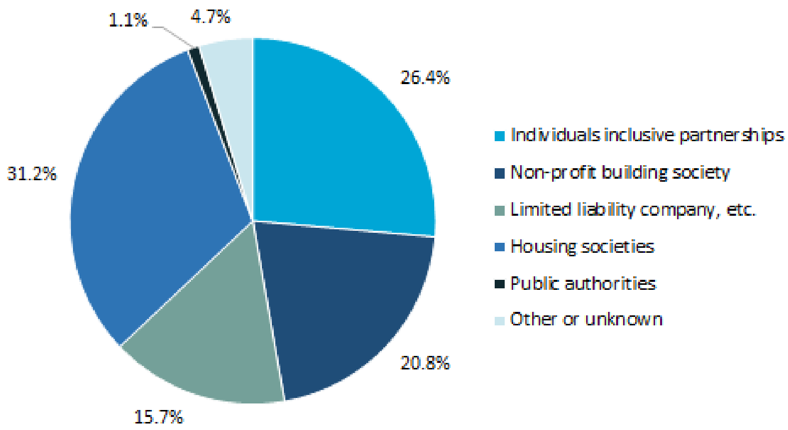


Figure 18 – Share of residents in multi-dwelling houses per building ownership type (for the CTR-area)

These people, all tenants, have an indirect influence on the DH distribution company through their HA or cooperative housing society (CHS). These HA's are generally also organised as cooperatives, thus representing their tenants through elected representatives, although its legal structure is different. In some cases, these HA- and CHS-representatives are also nominated by the HA to be in the board of the local DH company (Lund H. T., 2019). The HA's and CHS's have no direct influence on subjects like DH-prices or the distribution company's operations, but they do provide feedback, for example on the forward temperatures in the DH system and the minimum temperature requirement of the different buildings of the HA's and CHS's. Small maintenance on a building's heat delivery system (which is connected to the distribution system) is frequently done by the associations/societies themselves, although often through a collective service company (Lund H. T., 2019). The same goes for billing of heat for the different buildings and tenants of an association, for monitoring of delivery systems and for advice on major renovations, also often collectively (KAB, 2020).

For 'private' DH-consumers, thus people that own their own house and are not directly represented through some kind of organisation, things might be different. The way an individual consumer can influence the DH distribution company it is connected to depends on the organisational structure of the company. In the GC area all distribution companies are owned by municipalities or are cooperatives, as described under *Distribution*. Consumers that are connected to a municipal distribution system are represented in the board of the company in two ways; one is via municipal elections, as some of the DH company's board members are politically elected. The second way is through board members that are directly elected by the DH-consumers – both residential and non-residential/commercial consumers.

Consumers of a cooperative distribution company have a similar way of representation, although slightly different. For example the cooperative distribution company of Høje Taastrup Fjernvarme (HTF) has a board of nine people (Høje Taastrup Fjernvarme, 2020). Consumers are represented through direct elections where they can choose their board of directors and they are represented in a (larger) board of representatives (Birnbaum, 2019). However, the consumers are divided over three groups;

1. Owners of small buildings, smaller than 500 m^2. These owners have 1 vote each. They are not necessarily the residents of these buildings, although consumers that are owners of their own home, like a single-family house, are in this group. The first group has three representatives in the board of directors (BoD) and 15 members of the board of representatives (BoR);
2. Owners of large buildings, larger than 500 m^2. These owners have 1 vote per 500 m^2. Examples are housing associations or cooperative housing societies. The second group has two representatives in the board;
3. Commercial consumers. These owners also have 1 vote per 500 m^2. Examples are local shops (or their building-owners), larger commercial offices or factories and workshops. This group also has two representatives and, together with the second group, 20 members of the board of representatives.

Besides the seven BoD members that are elected by the different consumer groups, there are also two members that are directly appointed by the municipality of Høje-Taastrup. This way, the BoD consists of both consumer and municipal representatives, just like in municipally owned distribution companies. The distribution of these representatives and the way consumers have influence might differ, though.

5.1.1.3. Regulatory framework

The Danish DH sector is quite extensively regulated, compared to legislation on heating in other European countries (Henriksen, 2019). The main issues relevant to the DH sector that are either regulated by Danish law or subject to national or regional government policies are DH price regulation, regional heat planning, connection of buildings to DH and municipal sustainability, CO_2- and energy policies. The most important findings, relevant to the GC DH system, will be briefly described below.

Price regulation

By law Danish DH systems are regulated under a non-profit principle, as described in the Heat Supply Act. This concerns the whole supply chain, from production to delivery (Danish Energy Agency, 2017, pp. 16-17). The companies that are involved in one of the roles described in section 3.1 are subject to this regulation, like CTR and VEKS as transmission companies (CTR, 2014, p. 6) (VEKS, 2020, p. 7). Companies that do not fulfil one of these roles are not; parties that offer e.g. consulting services or fuel supply to a DH company are considered commercial activities and thus exempt from these regulations (Danish Energy Agency, 2017, pp. 16-17).

As Danish DH systems are to be non-profit, the question is what can and cannot be included in the DH price. The Heat Supply Act defines this can only include 'necessary expenses', among which could be for example fuel costs, personnel salaries, operational costs, costs for research activities, administrative costs or financing costs. Furthermore, operational depreciation costs, reserves for future (re-) investments and interest on invested capital may also be included in these necessary costs, but only with approval by the Danish Utility Regulator – Forsyningstilsynet (Danske Love, 2020) (Danish Energy Agency, 2017, pp. 16-17). However there are limits, as these companies may not cross-subsidize other activities in non-regulated sectors, like district cooling (Lund H. T., 2019).

The non-profit principle in the Heat Supply Act protects DH-consumers to unfair or disproportional price-setting, but does not protect to inefficient operation in the DH system or bad management. This is anticipated by the Danish Utility Regulator through obligatory transparency and (voluntarily) benchmarking of the total costs of the DH companies against similar other companies, both on the distribution and the transmission level (Folke, 2019) (Werling, 2019) (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 15). This way consumers not only know their DH-price is based on necessary expenses, they can also monitor this and object possible avoidable costs at the local board of appeal (Danish Energy Agency, 2017, p. 15).

Obligatory connection

Based on the Heat Supply Act and the policies that were formulated by the Danish government in the late 1970's and early 1980's, municipalities were given the possibility to impose an obligation to connect to a DH system on buildings in an area that was designated as a DH-area in regional heat plans (Danish Energy Agency, 2017, p. 12). The power to do this lies with the municipal council and results in mandatory payment of a fixed (annual) fee to the DH company, although in most cases this does not imply an obligation to buy and consume heat from the DH network too (Danish Energy Agency, 2017, pp. 16-17). Both new and existing buildings were subject to this, although for existing buildings a nine year grace period exists, provided that there are no scheduled replacements of heating installations before that. Exceptions are only possible when the consumer can show he/she lives in e.g. a low-energy single-family house (Honoré, 2019). However, regulation on obligatory connection to DH has been scaled back recently by the Danish government, as new buildings cannot be forced to connect anymore. Still, buildings with an existing DH-connection are obliged to stay connected nonetheless, although debate about setting those free too is ongoing (Holm, 2019).

Even though the possibility for imposing an obligatory connection seems to be slowly winded down, many stakeholders in the GC DH area mention this as a vital part of the successful development of the Danish DH sector in the last decades (McDonald, 2019) (Holm, 2019) (Folke, 2019). Some think the possibility to impose this obligation should not be removed from legislation, even though it is not exercised that much anymore, as it still is seen as important to in investment confidence (Department for Business, Energy & Industrial Strategy, 2020). One interviewee described the obligation to connect as: *"You pay for the opportunity to receive DH if you buy a house with a DH-connection."* On the other hand, this interviewee followed: *"From a historical point of view, this makes sense, although not everyone agrees that this should still be an obligation. It's not like, if they would tomorrow set all Copenhageners free, they would all run away. Actually, many even cannot do that, as not everyone has an alternative."*

Whether a consumer in the GC DH system has the obligation to be and remain connected to the system differs per municipality or even per neighbourhood. For example, within the distribution system of Høje Taastrup Fjernvarme some areas have a mandatory connection and some don't (Birnbaum, 2019). The different municipalities each have the power to impose this, or to not mandate a DH-connection (Honoré, 2019). One interviewee – roughly – estimated that this currently results in 25% of Danish DH consumers that have an obligatory connection that is still in place. In the GC system this is probably higher, in the city of Copenhagen – the catchment area of HOFOR – every consumer is still obliged to have a DH-connection and even to receive heat through the network in case of a commercial building or multi-dwelling house with annual demand of over 250 kWh (Honoré, 2019). This already is the case since 1984, when the Heat Plan of Copenhagen was adopted by the city council, and since the beginning benefitted from high public acceptance due to the great transparency in the heat planning process and the citizen participation in the DH company's operations. The obligatory connection is therefore widely seen as one of the main reasons for the success of the system (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, pp. 17-18).

Regional heat planning

Another regulatory factor that is mentioned as an important factor in the considerable development of the GC system is comprehensible regional heat planning. Additionally strong urban planning, focusing on high population density and resulting in efficient public services, is also indicated as relevant for the GC DH system's success (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 17). Since the Heat Supply Act of 1979 heat planning is the responsibility of the municipal governments and roughly consists of four steps:

1. Municipalities map the existing heat demand, heat supply method and amount of energy used and also estimate future heat demand and supply options;
2. Municipalities draft options for future heat supply, provinces/counties provide regional heat supply overviews;
3. Provinces/counties prepare regional heat plans, based on step 2, identifying priority of heat supply options and the location for future heat supply units and networks;
4. Based on the regional heat plans municipalities draft local heat plans including 'zoning' of areas that were to be supplied by DH or natural gas grids.

The fourth step of 'zoning' was not only aimed at establishing efficient urban energy systems, but also on preventing overinvestments in energy infrastructure by examining which areas were most viable for these systems. During the 1990's the heat planning process was updated and a new project approval procedure was introduced (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, pp. 13-14). New projects for establishing, expanding or changing DH- and natural gas systems had to go through a process for municipal approval (Danish Energy Agency, 2017, pp. 11-12). This approval was depending on the cost-efficiency of the proposed DH solution. The project proposal should therefore include user- and socio-economic, financial and environmental analyses that compare different alternatives for the heat supply, following a certain predefined methodology (Danish Energy Agency, 2017, p. 16). The Danish Energy Agency established guidelines for both drafting the proposal by the submitter and reviewing the proposal by the municipality (Lund H. T., 2019).

Currently, especially in the GC area, heat planning is not that 'active' anymore, as most energy infrastructures are in place (Nimb & Danekilde, 2019). In many areas there already is a DH system or a natural gas grid, or there is simply no potential for either of these two. Nowadays municipal heat planning is mainly focused on expansion of existing DH networks into areas that were formerly identified as natural gas areas, or on projects for establishing or replacing heat production facilities, for example in order to switch from coal to biomass in a CHP-plant (Nimb & Danekilde, 2019) (Henriksen, 2019). Especially expansion of DH systems based on waste incineration into natural gas areas is a relatively easy business case, as the waste incinerators are quite competitive due to their very low (fuel) costs (Folke, 2019).

Policies, goals and targets

Besides the 'harder' laws and regulation in the DH sector, there are also 'softer' instruments in the form of different policies, strategies, goals, (binding) targets, taxes and subsidies. These instruments do often use less 'force' and are directed at influence through stimulation, discouragement, raising awareness and initiating debate. Without elaborating too much on all kinds of different national policies and municipal strategies, a few examples and most important instruments will be mentioned below.

The Danish government established a national Energy Agreement in 2012 for the years up to 2020. Measures focused on the heating sector included amending the Heat Supply Act to stimulate converting coal to biomass in large CHP-plants, financial stimulus for small heat plants on biomass, promoting new technologies like geothermal energy and large-scale heat pumps and slowly banning individual oil-fired boilers from buildings (IEA, 2017). A new Energy Agreement was published in 2018, aiming for a 55% share of renewable energy in the total Danish energy consumption in 2030. For the DH sector the agreement is even more ambitious, with a goal for 90% of the DH use to be based on sources other than coal, oil and natural gas. It also incentivized the use of heat pumps and surplus heat in DH (Klima-, Energi- og Forsyningsministeriet, 2018, pp. 2, 8).

Another important and well-known instrument is the Copenhagen (CPH) 2025 Climate Plan, published by the city's government in 2012. The main goal of the plan is to make Copenhagen into the world's first carbon neutral capital in 2025. To achieve this goal the DH supply in Copenhagen needs to be carbon neutral in 2025 as well, which should mainly be reached by replacing fossil fuels with biomass in CHP-plants, by establishing new heat generation units like a geothermal facility and by converting peak load plants to carbon neutral fuels (City of Copenhagen, 2012, pp. 14-17).

Smaller municipalities also draft their own energy policies, like the municipality of Køge – located in the southwest of the VEKS-system – did in 2016. In their *'Strategic Energy Plan'* the municipality committed to a 40% reduction of greenhouse gasses in 2030, compared to their 2008-level. The development and expansion of a local DH distribution system in the municipality of Køge was one of the main methods to achieve this goal. Currently, there is a small but developing DH system in Køge, which was established in collaboration with VEKS (Køge Kommune, 2016).

Taxes and subsidies that are relevant for the DH sector are mainly:

- Exemption of CO_2- and fuel taxes for biomass in heat production (Varmelast, 2020)
- Subsidy for biomass in CHP on top of electricity market price (Varmelast, 2020)
- Exemption of the need for CO2-rights for production based on biomass (Varmelast, 2020)
- Stronger taxation on production using coal (Birnbaum, 2019)
- No tax in heat consumption, in contrast to taxes on electricity consumption (Birnbaum, 2019)
- Base load subsidy, for 15 years, for local CHP-plants after liberalisation of power market in 2003. Subsidy stopped in 2018 (Birnbaum, 2019) (Jessen, 2017)

More details on these taxes and subsidies can be found in section 5.1.1.4.

5.1.1.4. Economic parameters

Naturally, a DH system as large as the GC system requires large investments, which in turn need to be earned back over time. The business cases of the various elements have to be feasible individually and the system as a whole has to be able to generate an affordable heat price, whilst meeting the heat demand of all of its consumers at the times they need heating. To stimulate certain developments and (investment) decisions, a government can offer subsidies for or impose taxes on specific technologies, innovations or behaviour. This section will dive deeper into DH prices, demand, taxes, subsidies and the heat market.

District heating price

The heat price a consumer pays to the local DH company he or she is connected to differs per company. However, there is a certain degree of socialisation of DH prices in the GC system. As described under *Transmission* and *Distribution* there is one party, Varmelast, responsible for the central dispatch of production facilities in the GC system. This does not mean that CTR and VEKS, the transmission companies, both pay the same price, as they have different price agreements with production companies like Ørsted (CTR, 2014, p. 6). For historical reasons the contracts that CTR has with producers are slightly better than the contracts VEKS has, resulting in different heat prices (Werling, 2019). However, the price VEKS charges all of the 19 distribution companies that are connected to its network is the same, as transmission costs are socialised over all VEKS' consumers. The same goes for CTR and its 5 distribution companies (Holm, 2019) (CTR, 2014, p. 6). In turn, the price the distribution companies charge their consumers is different; HOFOR and Frederiksberg Forsyning, two distribution companies that are connected to the CTR-network, have different heat prices for their consumers as e.g. the physical characteristics of their networks are different, they might have different salary schemes, etc. Lastly, the distribution companies socialise their costs over all connected consumers, resulting in one single heat unit price for every consumer (Honoré, 2019). The only differentiation in the final consumer heat price is in the fixed costs for e.g. the size of the connection, as the variable part in €/GJ is identical for every consumer. This GJ-price is independent from the forward temperature level, although there could be some differentiation based on the return temperature of a consumer, as is shown in the bonus/malus system of HOFOR, where you receive a bonus on your heat price for a low return temperature and vice versa for a high temperature (Honoré, 2019).

As said, the price individual consumers pay for their heat consists of a fixed and a variable part and both the fixed and variable part generally differ per DH distribution company. On average 72% of total costs for a Danish DH company are for heat production and 23% for distribution of this heat to the end-users, according to the Danish Energy Agency (2017, p. 16). For the GC area this division assumedly is different, as produced heat is centrally dispatched and therefore produced more efficiently, probably resulting in a lower share for production and relatively more costs for distribution.

The national average household expenses on heating through DH increased by 6% in 2019. This calculation is based on a 'typical' (single-family) house of 130 m² and with an average heat demand of 18.1 MWh/year or 65.2 GJ/year, resulting in total costs of DKK 12,859 or € 1,725.09 per year (Dansk Fjernvarme, 2019, p. 2). The 6% price increase was said to have followed a price 'normalisation' after an extraordinary price reduction of one large heat supply company the year before. Furthermore, the baseload subsidy for small CHP-plants – that was mentioned under *Policies, goals and targets* in the previous section – was stopped after 15 years in 2018, which also explains a part of this 6% price increase (Dansk Fjernvarme, 2019, p. 2). The development of the average yearly costs for DH of a typical house can be seen in Figure 19.

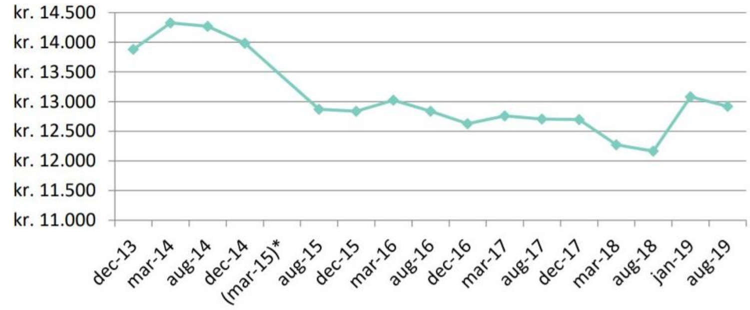


Figure 19 – Development of weighted average DH expenses for 'typical' household of 130 m² and demand of 18.1 MWh/year in Denmark (Forsyningstilsynet, 2019)

To provide some insight on the burden of energy costs on an average Danish income, some extra data is needed. Danes have an average income of DKK 326,048 or € 43,737.19 per year, before tax. An average family, a couple with two children, has an income of around DKK 984,453 or € 132,057.87 per year. The average energy bill – electricity, gas, heat, other fuels – of a Danish family was around DKK 23,940 in 2018. For an average family with two children, this would mean that around 2.4% of yearly income before taxes is spent on energy (Statistics Denmark, 2020). In the same year, an average single-family house paid DKK 12,859 for DH, which means a two-children family would use around 1.3% of its income before tax on its heating bill. The Danish Energy Agency stated DH-prices in 2017 averaged around 1.7% of a household income, before taxes and VAT (Odgaard, 2019, p. 2).

Heat demand and density

As was explained in section 3.2.1 the heat demand density (HDD) of a DH system is vital to its viability. It is often stated that the average investment costs are strongly correlated with HDD; costs per sold GJ increase exponentially when HDD decreases, as was shown in Figure 4. Where the HDD of a certain area is influenced by factors like average building insulation, population density and heating degree days (climate), the HDD of the system is also influenced by the connection density of consumers to the system. As already in the 1980's the Danish municipalities were allowed to impose an obligation to connect to DH on its citizens, the connection density of the areas where DH was planned is often very high.

This is also the case in the GC system, especially when a municipal government identified almost all of its territories as DH-area, like in municipalities such as Copenhagen or Frederiksberg, both with a 95% market share for DH. In Figure 20, on the next page, the heat demand densities for the various municipalities in the GC DH system can be seen. This shows the area has a high HDD, especially in the larger municipalities the city centres have high heat demands. Furthermore, the VEKS area clearly has a lower HDD than the CTR area, which is probably the reason the CTR area shows a 86.6% market share for DH and the VEKS area only 53.7% (Statistics Denmark, 2020). Due to the Danish laws and regulation on (municipal) heat planning and obligatory connection, as discussed in section 5.1.1.3, the connection density is quite high in the areas that are assigned to DH, also in the VEKS region.

Taxes and subsidies

The Danish national government is responsible for (fiscal) legislation on energy taxation and offering subsidies for stakeholders in the energy sector. There are a few policies that affect the DH sector – briefly mentioned under *Policies, goals and targets* in section 5.1.1.3 – as taxes and subsidies have been used to stimulate sustainable heat production since the 1970's (Danish Energy Agency, 2017, pp. 12-13). The most important taxes and subsidies in Danish national and local energy policy will be briefly described.

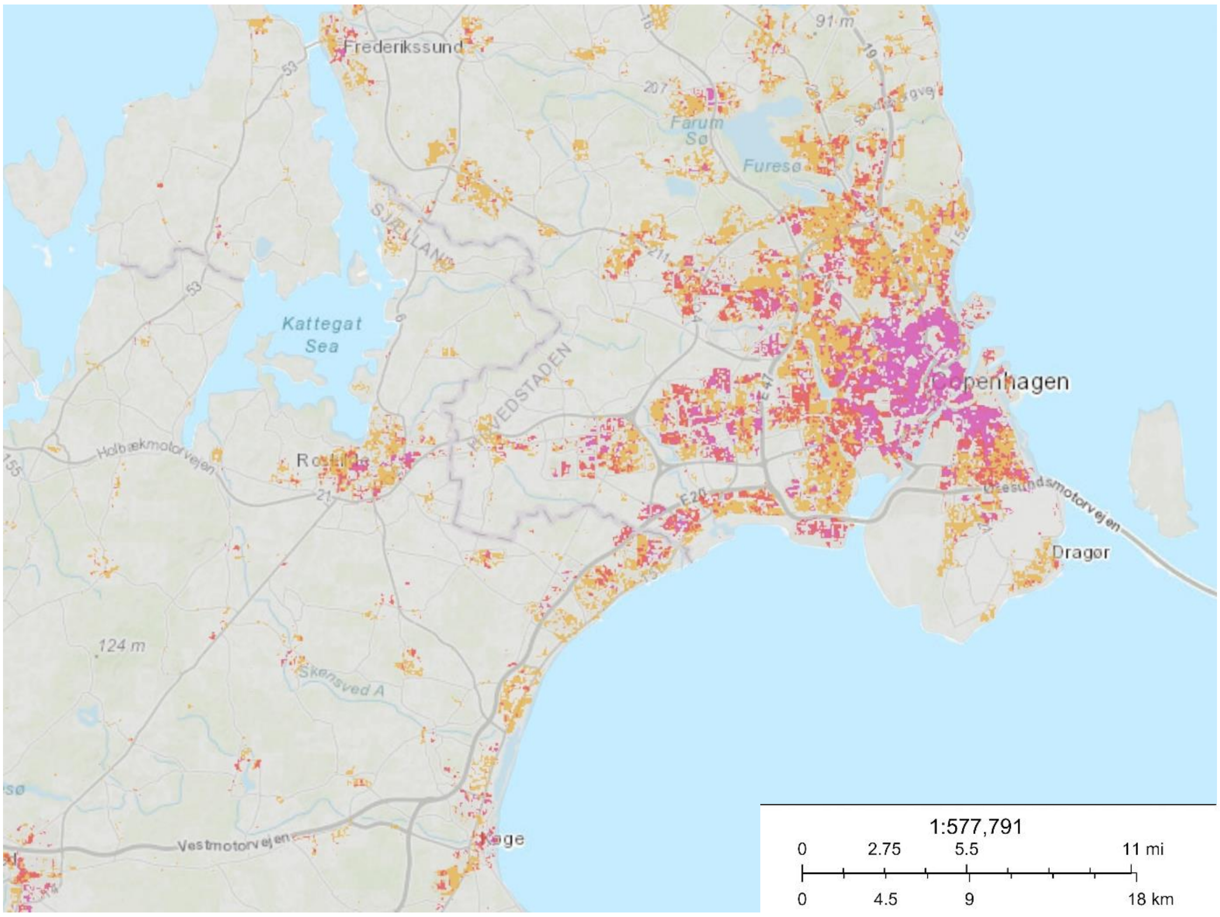


Figure 20 – Heat demand densities (2015) for Greater Copenhagen area. Areas in purple are >300 TJ/km², in red 120-300 TJ/km² and in orange 50-120 TJ/km². Source: (Heat Roadmap Europe, 2020)

Biomass in DH has been stimulated by the Danish government for years and still is a vital part of the Danish energy transition. Largest benefits for biomass come from the exemption of CO_2- and fuel taxes when used for heat production (Birnbaum, 2019) (Danish Energy Agency, 2017, p. 12), from a subsidy for biomass used in CHP of €20/MWh on top of the electricity market price (Danish Energy Agency, 2017, p. 7) and from the exemption of the need for CO_2-rights (Varmelast, 2020). In contrast, coal is quite heavily taxed, even more when prices dropped in the 1980's, as these policies aim exactly at replacing coal with natural gas and biomass (Danish Energy Agency, 2017, pp. 12-13).

Furthermore, electricity consumption is much more heavily taxed than heat consumption (Birnbaum, 2019). In fact, electricity consumption is taxed, where (district) heat consumption is not (directly) taxed at all. Furthermore, taxation on fuels used for electricity production is different from taxation on fuels used for heat production, as the first is levied on end-user consumption of electricity and the latter is directly charged on fuel use for heat production (Danish Energy Agency, 2017, p. 19). To overcome challenges that are presented by this taxation scheme for heat pumps and electric boilers in DH systems, tax is reduced for electricity used for DH production (Danish Energy Agency, 2017, p. 22).

On the subsidy-side there are no direct subsidies on transmission, distribution, delivery or consumption of DH. The only Danish subsidies that affect DH are on the production side, like the earlier mentioned subsidy for heat production based on biomass in CHP-plants. Before 2019 decentral CHP-plants received a subsidy for electricity production as a feed in tariff on top of the electricity spot market price, later converted to a fixed annual amount. After 2018 only the feed-in subsidy of €20/MWh above the electricity spot price for biomass-based CHP-plants remained (Danish Energy Agency, 2017, p. 19). There are however some subsidies for research and development projects outside the production of heat, like for a Pit Thermal Energy Storage (PTES) project in the municipality of Høje-Taastrup. However, this is a subsidy from the European Union, not from the Danish government (Birnbaum, 2019).

Although it is not a subsidy but more like an investor guarantee or stimulus, another important policy that needs to be mentioned is the possibility to secure loans from a common municipal credit scheme (Odgaard, 2019, p. 4). This results in lower financing costs for municipally-owned DH companies and in many cases the same applies to cooperatively owned DH companies, which is often the reason for municipal representation in the board of a cooperative DH company (Birnbaum, 2019). Lastly, subsidy policies are designed to be cost-neutral for the Danish state, as these are to be compensated by the CO_2- and energy taxes (Odgaard, 2019, p. 19).

5.1.1.5. Future challenges

Even though the district heating sector in Greater Copenhagen – and all of Denmark – is very mature and well-functioning, there still are challenges to be seen for the coming years. These challenges may concern the economic situation, ambitious policies, technological issues or societal trends. This last part of section 5.1.1 covers the challenges that came forward during stakeholder and expert interviews. The most prominent challenges are briefly described in the list below. These challenges might regard to Denmark in general and/or the GC DH system in particular:

- Many of the interviewees argued that biomass is widely considered as a temporary solution in the transition towards renewables in DH (FORESIGHT Climate & Energy, 2019). However, it is far from clear what the alternative heat sources will be when the use of biomass is brought down;
- The more than 20 distribution companies within the GC system are highly dependent on only a few large heat producers that cover the vast majority of the heat supply. This is not considered a problem for the security of supply, especially during summer, but it leads to being heavily reliant on these producing companies due to the lack of competition and absence of alternatives;
- The possibility to increase the role of decentralised production is discussed regularly as a means of increasing security of supply and slowly replacing the large CHP- and waste incineration plants with smaller and lower temperature renewable heat source, but is also subject to barriers like a maximum share for decentral production that is agreed upon by the DH companies;
- In their municipal climate agreement the City of Copenhagen established a goal to become the first carbon neutral capital in the world by 2025. As praiseworthy as this might be, it can be considered a major challenge to reach this goal. Besides, even when this goal is reached, an important part of the solution will come from the use of biomass. However, many stakeholders agree biomass should be a temporary solution, even policymakers, like the ones of the City of Copenhagen, agree with this;
- The prices end-user of DH pay are fixed prices, simply in Danish kroner per GJ. Some stakeholders and researchers challenge this fixed price and deliberate whether a fluctuating price – varying between seasons, or even per hour – could better reflect the actual production costs, help balancing supply and demand and support the use of renewables, for example when intermittent renewable electricity production is used for heat production through heat pumps;
- Heat production from waste incineration is often extremely cheap. Some stakeholders consider heat from waste incineration as unfair competition for renewable heat sources and think this could hamper the development or renewable heating in the short term, even though waste incineration could be expected to be reduced due to increasingly circular use of resources in the long term;
- Some stakeholders warn for financial risks for DH systems because of abolishing the obligatory connection;
- Surplus heat production – for example from commercial buildings or industrial processes – faces a hard business case as third-party producer, for example because of the extremely cheap heat from waste incineration and the very competitive business case of large-scale CHP production. This is a challenge to utilising the surplus heat that is now lost;
- Buildings in Copenhagen and neighbouring municipalities are often far from 'ready' for a lower (forward) temperature in the DH system. This is due to a lack of insulation or a poor heat delivery system. This is for example the case in many buildings that are owned by housing associations that do not have a large budget for building retrofits or renovation;
- The large production plants create a lock-in, both because of the high investments that are made and the long-term contracts they have with DH companies. This is considered a problem for introduction of renewable and often smaller-scale heat sources;
- The differences in heat supply and demand between seasons can be a challenge in reaching a viable business case for third-party producers. One possible solution is to create more storage capacity, but that is often still (considered) too expensive;

5.1.2. Amsterdam

The district heating system of Greater Amsterdam is – in contrast with the situation in Greater Copenhagen – not one large, integrated system, but consists of several separate district heating systems in the city of Amsterdam and neighbouring municipalities. In this section the main focus is on the two large DH systems in the municipality of Amsterdam, but systems in neighbouring towns and cities are briefly described too, all along these five main subjects: the historical development, current system, regulatory framework, economic parameters and future challenges.

5.1.2.1. Historical development in the Netherlands and Amsterdam

Even though the Dutch district heating sector is not very large, especially compared to the extensive natural gas grid, DH already has a long history in the Netherlands. In 1923 Utrecht was the first Dutch city with a DH network, where steam was delivered from a decreasingly used power plant at the edge of the old city centre to a hospital nearby (Den Hartog, 2014, pp. 1-2). The Utrecht DH system still is one of the largest networks in the Netherlands, with currently, including neighbouring municipalities like Nieuwegein, around 55,000 connections and a yearly supply of 3.1 PJ (Segers, Van den Oever, Niessink, & Menkveld, 2019). In the Netherlands DH has never been specifically stimulated or been made a priority by the national government. Still, there are approximately 400,000 houses in the Netherlands connected to DH, of which more than 300,000 houses are connected to large-scale DH systems, defined as systems that deliver over 150 TJ annually (Segers, Van den Oever, Niessink, & Menkveld, 2019, p. 5). When looking at total heat delivery a rough 23 PJ was deliver through DH in 2016. Of this amount around 50% was delivered to households, 25%-30% to commercial consumers and 15%-20% to agriculture (Segers, Van den Oever, Niessink, & Menkveld, 2019, p. 5). The share of heat consumption through DH for agriculture is quite remarkable, compared to other countries. This mainly relates to geothermal energy for the horticulture sector, which is very large in the Netherlands and whose greenhouses account for an important part of DH consumption.

In Amsterdam the DH system consists of two parts that are owned by different entities, although they are increasingly connected. The two parts – Northwest and Southeast – were developed separately and out of different initiatives. The Southeast part of the system was initiated because a new power plant was to be built in Diemen, a municipality almost enclosed by the municipality of Amsterdam. The provincial government of Noord-Holland would issue a permit for building this plant to the publicly owned (municipalities and provinces) production company UNA, but only on the condition the surplus heat of the plant would be made useful (Buijck, 2019). In order to meet this condition, UNA approached large housing associations that owned big apartment buildings in the Bijlmer district. The connection of these – mainly social housing – buildings via a DH network to the new plant was an important part of complying with the conditions set by the provincial authorities. After years of mergers between municipal and provincial energy companies and consequent liberalization and/or unbundling of these companies – partly based on EU legislation – the south-eastern part of the DH system is now fully owned by the Dutch branch of the Swedish state-owned energy company Vattenfall (Vattenfall, 2020).

The Northwest part of the DH system had a slightly different origin. Around 1996 and 1997 the local municipal distribution company for electricity and natural gas proposed to establish a DH network to make use of the excess heat of the waste incineration plant that was located in the district of Sloterdijk (Buijck, 2019). After this the search for an appropriate area to establish a DH grid started, resulting in a physical scope that was somewhat smaller than anticipated in order to reduce (financial) risks. The Westpoort region was selected, a (former) harbour area that mainly consisted of commercial and industrial buildings. After a period of orientation, contacting different businesses and securing a declaration of intent of 75% of the market of 120 pre-identified commercial buildings, the board of the energy company decided to establish the DH network. In 1999 the DH company *Westpoort Warmte* (WPW) was established, a joint venture between the municipality (50%) and the energy company (50%), the latter now belonging to Vattenfall NL after a series of mergers and acquisitions in the following 20 years. This northwestern part of the Amsterdam DH system was supplied with heat by the waste incinerator that was owned by the municipality of Amsterdam and, since 2014 is an independent, but municipally-owned company called *Afval Energie Bedrijf Amsterdam* or *AEB Amsterdam* (AEB) (AEB Amsterdam, 2020).

After being separated for roughly two decades, the two main system parts are now being physically connected in the southwest of Amsterdam. The project, called Amsterdam South Connection, establishes a 3.8 km long transmission pipe that connects the Nieuw-West area (WPW, northwest) to the Zuideramstel/Zuidas area (Vattenfall, southeast). At the same time a small back-up/peak load plant on natural gas and a 3,600 m^3 or 30 MWth thermal storage are built (Vattenfall NL, 2020). Given the fact that Vattenfall is the full, integrated owner of the Southeast system and has a 50% stake in the WPW joint venture, this makes Vattenfall the main party in this connected or integrated Amsterdam DH system.

Besides these two large networks and the two major stakeholders within the municipality of Amsterdam – Vattenfall and the municipal government itself – there also have been some minor developments and initiatives over the years. One of these is a citizen cooperative, *MeerEnergie*, that has the ambition to build and operate a DH system in Watergraafsmeer, a neighbourhood of Amsterdam (Nicolaï, 2019). There are only a few DH-cooperatives in other parts of the Netherlands, in contrast to the approximately 340 DH-cooperatives in a country like Denmark, which together deliver around 30% of all heat through DH in the country (Jessen, 2017, p. 2). Just like in Denmark, the MeerEnergie cooperative is relatively small, compared to the larger DH networks that were developed under municipal ownership. MeerEnergie aims to connect a minimum of 5,000 houses (MeerEnergie, 2019). More on this in section 5.1.2.2.

Outside of the municipal boundaries of Amsterdam, there are quite some other DH systems, both relatively small and larger. In the neighbouring municipalities of Aalsmeer, Almere, Amstelveen, Diemen, Haarlem, Purmerend and Zaanstad there are DH networks, either quite small or still developing (Aalsmeer, Haarlem, Zaanstad), large and more mature (Almere, Purmerend) or connected to or part of other DH grids (Amstelveen, Diemen). The next section will further elaborate on these DH systems.

5.1.2.2. Current DH system of Greater Amsterdam

When describing the DH system(s) of Amsterdam, two main areas will be distinguished. When the DH system(s) of *Amsterdam* will be discussed, this will refer to both the system in the Northwest of Amsterdam, operated by Westpoort Warmte (WPW) and the system in the Southeast of Amsterdam, operated by Vattenfall. When the DH system(s) of *Greater Amsterdam* (GA) will be discussed, this will not only refer to the systems of WPW and Vattenfall in the municipality of Amsterdam, but also to DH systems in neighbouring municipalities, like Aalsmeer, Almere, Amstelveen, Diemen, Haarlem, Purmerend and Zaanstad. Only the city of Lelystad is excluded from this definition as it is considered too far from the city of Amsterdam, even though it is a participant in the Amsterdam metropolitan area partnership.

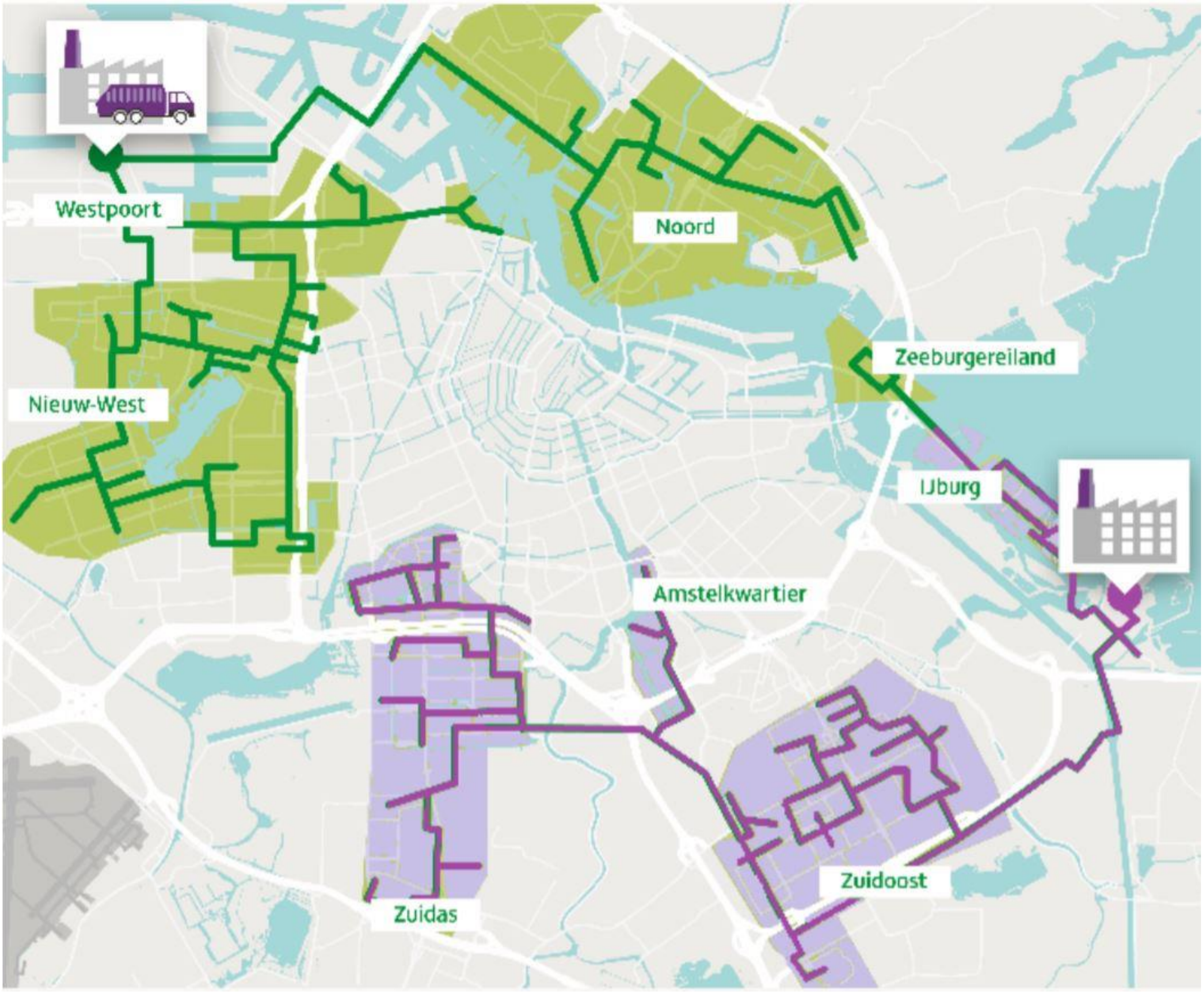


Figure 21 – Map of the two DH systems in Amsterdam: the southeastern system is owned by Vattenfall (in purple), the northwestern system is owned by WPW (in green). In 2019 Vattenfall started to connect both systems, which is not visible on this map (Rekenkamer Amsterdam, 2018)

This section is divided in three parts, similar to the previous case study of Copenhagen, but in this case transmission and distribution will be discussed together. In Figure 21 the two systems in Amsterdam are already shown as these have been the main focus for this case study. The other DH networks in the Greater Amsterdam region will only be discussed briefly and when relevant. An overview of the GA region is provided later in this case study.

Production

The production facilities in the Amsterdam DH system are orderly divided over the two parts of the system. The northwest part of the system – from now on called the *WPW system*, as it is owned by the *Westpoort Warmte* joint venture between the municipality of Amsterdam and the company of Vattenfall – is supplied by the large waste incinerator of AEB. This waste incinerator, located near the Amsterdam harbour and northwest of the city centre, produces both electricity for the grid and heat for the WPW DH system. Through their 100% ownership of AEB, the municipality of Amsterdam indirectly owns this waste incinerator. The AEB-plant consists of a 'regular' waste incinerator with 4 incineration lines since 1993 and added a 'highly efficient' waste incinerator with 2 incineration lines in 2007. The total capacity of the plant could be, by estimation, around 250 MWth in 2040 (Segers, Van den Oever, Niessink, & Menkveld, 2019, p. 28). AEB has an obligation to produce and supply a certain amount of heat to the WPW system (Van Zanten, 2019). In 2014 the board of AEB raised the maximum capacity it guaranteed to supply to WPW from 100 MWth to 150 MWth (Rekenkamer Amsterdam, 2018, p. 44). In the last publicized figures of 2017 AEB supplied 918,785 GJ to the WPW DH network, of which 80% was generated in the 4 regular incineration lines, 15% in the 2 high efficiency incineration lines and the remaining 5% in a smaller biogas facility (AEB Amsterdam, 2018). A second small biogas/anaerobic digestion plant, with a capacity of 5.5 MWth and owned by Orgaworld, also supplies a small amount of heat to the WPW system (Segers, Van den Oever, Niessink, & Menkveld, 2019, pp. 26-27) (Orgaworld, 2020) and in 2019 WPW added 300 m^2 of solar collectors with an estimated annual output of 450 GJ to the system (Vattenfall, 2019).

The southeast part of the system, fully owned and operated by Vattenfall and from now on called the *SE system*, is mainly supplied by the CHP-plant in the municipality of Diemen, close to Amsterdam. This facility, also fully owned by Vattenfall, consists of two CHP-plants that are both fired by natural gas and together have a thermal capacity of 615 MWth (Vattenfall, 2020). There also is a storage tank with a capacity of 22,000 m^2 that functions as a heat buffer and can deliver heat for 8 to 16 hours, depending on the season (Vattenfall, 2020). Besides this CHP-plant, Vattenfall aims to build a biomass-fired heat-only boiler on the Diemen-site, next to the other plant. This plant is supposed to have a thermal capacity of 120 MWth and supply heat to the Vattenfall DH system (Vattenfall, 2020). However, although permits already have been granted by the provincial authority, there is a lot of resistance against this plant in local communities and politics (Ranzijn, 2020) (McDonald, 2019) and, lately, also in national politics (Het Parool, 2020) (NOS, 2020). Because of this societal resistance and political opposition, Vattenfall very recently decided to postpone the final investment decision for the biomass-plant with a year to after the summer of 2021 (Vattenfall, 2020).

The Diemen CHP plant not only supplies the SE system (including Diemen), but also supplies a part of the municipality of Amstelveen, south of the Amsterdam financial district. Although the grid in Amstelveen is physically connected to the SE system's transmission line, it is however supplied by Eneco, a large Dutch energy company that also has many (large) DH systems in the provinces of Utrecht and Zuid-Holland. Besides Amstelveen another large DH system, also owned by Vattenfall, in the city of Almere is supplied by the Diemen plant, for which a 8.5 km long transmission line is installed in the *IJmeer* lake. This supply by the Diemen-plant to the Almere system is supplemented by two peak load/back-up plants on natural gas and by a 7,000 m^2 solar thermal plant with a yearly production of almost 10 TJ, located in the north of Almere (Segers, Van den Oever, Niessink, & Menkveld, 2019, p. 27) (Vattenfall, 2020).

Other DH systems in municipalities around Amsterdam are supplied by a range of production facilities. Noteworthy is the DH system of Purmerend, a city of 80,000 citizens, as roughly 75% of all inhabitants is supplied by DH, which is the highest market share for DH in the Netherlands (Segers, Van den Oever, Niessink, & Menkveld, 2019, pp. 38-39). This system is mainly supplied by a 44 MWth (heat-only) biomass plant, owned by the local, municipally owned DH company. Besides these, there also are two natural gas-fired peak load plants of 90 MWth and 35 MWth (Loogman, 2020). A total of 0.9 PJ was delivered through this DH system. Other (planned) DH systems in Aalsmeer, Haarlem and Zaanstad are (going to be) supplied by biomass, geothermal energy or surplus heat from data centers (Warmtenetwerk Zaanstad, 2020) (Firan, 2020) (Joosse, 2019).

Transmission/distribution

As in Amsterdam there is – in contrast to Copenhagen – no large transmission network and no DH-company that only operates a transmission grid, the roles of heat transmission and heat distribution are discussed together in this case study. In Amsterdam and its surrounding municipalities DH systems are generally more locally orientated and thus do not transport heat over very long distances to separate distribution grids. Only the systems of WPW, Vattenfall (southeast Amsterdam), Almere and Purmerend can be classified as large DH systems (Segers, Van den Oever, Niessink, & Menkveld, 2019, pp. 24-28, 38-39). Within these DH systems there is a primary and secondary distribution grid and (often) a larger transportation pipe from a main, central heat source to the distribution grid.

In case of the WPW system, this would mean there are transmission pipes from the AEB waste incinerator to the primary distribution grid in Amsterdam (Nieuw-) West and one to the Amsterdam North primary grid, as can be seen in dark green in Figure 21. This transmission pipe continues into the primary distribution grid which then, through different sub-stations, transfers heat to the secondary distribution grid which is connected to end-users (Vattenfall, 2020). The temperature level in the WPW system varies from 120°C/95°C feed-in temperature at the source (depending on the season) to 70°C delivery temperature at the end-user (Van Zanten, 2019).

The SE system of Vattenfall covers – roughly – four areas in Amsterdam and a small part of Diemen. The area around *IJburg* is relatively close to the Diemen CHP-plant, the districts of Amsterdam *Zuidoost* (including Diemen), *Zuidas* and *Amstelkwartier* are somewhat further apart from each other and their main heat source. There is a main transmission pipe from the Diemen-plant to the Zuidoost district and subsequently to the other districts. Within each of these areas there is, again, a primary and secondary distribution grid, as is shown in Figure 21. All of these are owned and operated by Vattenfall: the Diemen-plant, the transmission grid and distribution grid(s). Within these areas Vattenfall thus is a vertically integrated monopolist: it controls all parts of the value chain – from production to transmission, distribution and delivery – and within this system it is the only party that's active in these roles. The temperature level in the system varies, roughly between 120°C/90°C feed-in temperature, depending on the season, to around 70°C delivery temperature at the end-user (Buijck, 2019). As the DH system of Almere is also supplied by the Diemen CHP-plant, there is a large, 8.5 km long transmission pipe from the plant to the distribution grid of Almere (Segers, Van den Oever, Niessink, & Menkveld, 2019, p. 27).

In many cases, especially in the smaller DH systems, it is hard to distinguish between transmission infrastructure and distribution grids. Many DH systems just consist of a distribution grid and only have a transmission line from the central heat source to this grid. In the examples of the WPW network this seems to be the case, but with the exception that the West and North part of grid are only connected through a transmission line via the AEB-plant, but still form one 'integrated' system. In the case of the SE system and the Almere system, there even are two separate DH systems that do not exchange heat, although these are owned and operated by the same vertically integrated, monopolistic DH company. What makes this part of the system even more interesting is the fact that the DH grid in the municipality of Amstelveen is physically connected to the SE system and also supplied by the Diemen-plant, but it only takes around 5% of the total heat demand in the SE system and the Amstelveen grid is owned and operated by a different DH company; Eneco (Segers, Van den Oever, Niessink, & Menkveld, 2019, p. 24). This perhaps makes the distinction between transmission and distribution grids even harder.

Although growth of the SE system is projected, expanding the system requires additional production capacity, but the capacity of the Diemen-plant is limited (Menkveld, Matton, Segers, Vroom, & Kremer, 2017, p. 40). There also is an ambition of both Vattenfall and AEB to be able to connect more sustainable sources, which is believed to be better feasible by connecting the two systems (Vattenfall, 2019). The Diemen CHP-plant supplies heat to both the SE system and the Almere DH grid, which already have a combined demand of almost 120,000 household equivalents (HEQ) and over 3.7 PJ annually. However, there still is overcapacity in the WPW system. In order to fully utilize this overcapacity in the WPW system, making better use of (the renewable share of) heat from waste incineration and to be able to connect more sustainable sources Vattenfall and WPW are currently working on physically connecting these two systems with an additional 3.8 km of transmission pipe in the southwest of Amsterdam (Vattenfall, 2019, pp. 2-5). This project, called the "Amsterdam South Connection", is expected to be finished in 2022.

Besides these WPW, SE and Almere system, there is a fourth large DH system in the GA area; the network of the city of Purmerend. As mentioned earlier, with 75% this is the municipality with the highest market share for DH in the Netherlands. The local DH company, *Stadsverwarming Purmerend*, is owned by the municipality and operates the distribution grid, the 44 MWth heat-only biomass plant, which covers 70% of total supply, and two natural gas fired peak load boilers, covering 30% of supply (Stadsverwarming Purmerend, 2020). The temperature in the network varies between 90°C and 50°C (Stadsverwarming Purmerend, 2017).

District heating systems in neighbouring municipalities are either still developing and/or relatively small. In Aalsmeer, Haarlem and Zaanstad there are systems that are currently being developed or have recently been established:

1. In Aalsmeer a low temperature (LT) DH system has recently been developed in a public-private partnership. A consortium of four organisations supplies excess heat from a large data center to the grid, which is then being transported to a public educational building, a public swimming pool and a private horticulture company (Hamer, 2019).
2. In Haarlem there are two initiatives;
    a. A collaboration between the municipality, Firan – a public DH company – and three housing associations that investigates the possibility to develop a DH system with biomass or geothermal energy as a source and up to 6,000 connected houses (Gemeente Haarlem, 2019)
    b. A collaboration between the municipality, a local citizen foundation and Delft Technical University that studies the opportunities for a LT DH system with thermal energy storage, solar thermal + PV panels, individual heat pumps and improved insulation for over 1,100 houses (HIER verwarmt, 2018).
3. In the city of Zaanstad a DH system is being developed by several housing- and homeowners associations, the municipality, Firan, biomass-operator Bio Forte and energy company ENGIE. Remarkable about this system is the unbundling of roles in the DH value chain: ENGIE will be the heat provider, Warmtenetwerk Zaanstad – a joint venture between Firan, the municipality and a provincial investment fund – will be the DSO and Bio Forte will be the heat producer (Firan, 2020). Warmtenetwerk Zaanstad has the ambition to develop into a DH system with multiple producers and providers.

Consumption

To be able to understand the consumer-side of a DH system, it is important to know something about (at least) three things: total heat demand in and number of connections to the system, the type of consumers and the type of buildings these consumers use. However, this information may not always be accessible or even available. Especially in smaller DH grids, systems that are still to be developed or in privately owned systems this information might be minimal. In Greater Copenhagen many different distribution systems are connected via a central transmission system and therefore function as one integrated and almost entirely publicly or cooperatively owned system. The size, maturity and ownership structure of this integrated system ensure transparency and access to information. Within the GA area there are several DH systems that are smaller and, in most cases, not connected to each other. Access to and availability of information is therefore much more limited. The consumer-side of these systems will be described as good as reasonably possible, using publicly available information and interviews with selected stakeholders.

When looking at Amsterdam, DH-consumers are divided over the WPW system and SE system, including Amstelveen. In 2018 the WPW system was estimated to have around 15,000 connections that together consumed 0.9 PJ. Of these connections roughly half is a single dwelling and the other half consists of multi-dwelling or commercial buildings with a collective connection (Segers, Van den Oever, Niessink, & Menkveld, 2019, pp. 25-26). These 15,000 connections and the share of building types roughly correspond to the 34,333 household equivalents (HEQ) that Vattenfall reported for 2019 (Vattenfall, 2020). The WPW system has many connections in the *Nieuw-West* district of Amsterdam, which stretches out over roughly half of the WPW catchment area (see Figure 21). This district is very densely populated: 9,015 inhabitants/km^2 (CBS, 2020), even much denser than the municipality of Amsterdam as a whole, with 5,214 inhabitants/km^2 (CBS, 2020). In the Nieuw-West district around 70% of all dwellings is tenant-occupied, comparable to the average for Amsterdam. The share of dwellings that is owned by a housing association is even higher than average; almost 50% for Nieuw-West and 41% for Amsterdam (CBS, 2020). For other municipalities in the GA area the share of tenant-occupied dwellings is much lower, as Figure 22 shows. As can be imagined, housing associations are thus an important party in the energy transition for Amsterdam (Gemeente Amsterdam, 2020).

The SE system is larger than the WPW system, not necessarily in terms of catchment area, but mainly in terms of number of connections and total heat supplied. It stretches out over the *IJburg*, *Zuidoost*, *Amstelkwartier* and *Zuidas* (incl. a part of Amstelveen) districts/neighbourhoods, which together encompassed 19,000 connections and a heat demand of 1.8 PJ in 2018 (Segers, Van den Oever, Niessink, & Menkveld, 2019, p. 25). Vattenfall stated this would correspond to 48,683 HEQ in 2019, however this number does not include the consumers on Amstelveen grid, as these are supplied by Eneco (Vattenfall, 2020). Like the WPW system this grid is located in a densely populated area; for example the Zuidoost district has a density of 7,083 inhabitants/km^2, the DH-part of Amstelveen 8,076/km^2 and the Zuidas area even 10,526 /km^2 (CBS, 2020). In all of these areas multi-dwelling houses like apartment blocks and terraced houses are prevalent. However, the share of tenant-occupied houses and of HA-owned houses is lower in a more suburban area like (the DH-part of) Amstelveen; 49% and 29% respectively. In the Zuidoost district, especially around the *Bijlmer* neighbourhood, the share of tenants and especially HA-ownership is much higher; 71% and 55% respectively (CBS, 2020). In general HA-ownership is especially present in the GA DH systems (Van Zanten, 2019).

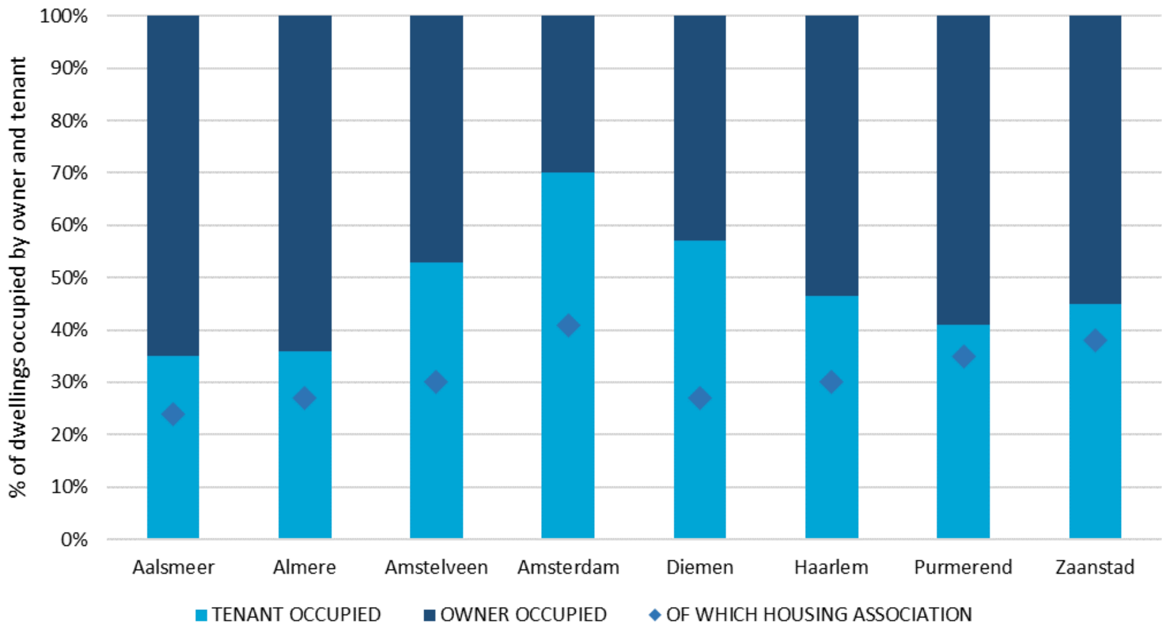


Figure 22 – Share of owner- and tenant-occupied dwellings per municipality. The part of tenant-occupied dwellings that is owned by housing associations is also given (CBS, 2020)

The two parts of the Amsterdam DH system are relatively large, for Dutch standards. This is not surprising, as Amsterdam is – by far – the largest municipality within the GA area, as can be seen in Figure 23. However, the DH system of Almere is, in terms of connections to the system, even larger than the Amsterdam DH system parts combined. On the other hand, the Almere system is smaller in terms of household equivalents and heat supplied, with 68,367 HEQ and 1.9 PJ annually (Vattenfall, 2020). This is probably due to the fact that the municipality of Almere as a whole is not that densely populated, as is shown in Figure 24. However, being a relatively young city on a land reclamation that's just over 50 years old, Almere covers a large area but was subject to thorough urban planning, resulting in a municipality with a handful of relatively dense residential and commercial districts, interrupted by "empty" areas with few inhabitants. This explains the fact that DH is still viable in certain parts of Almere, even though the population density of the whole municipality is low.

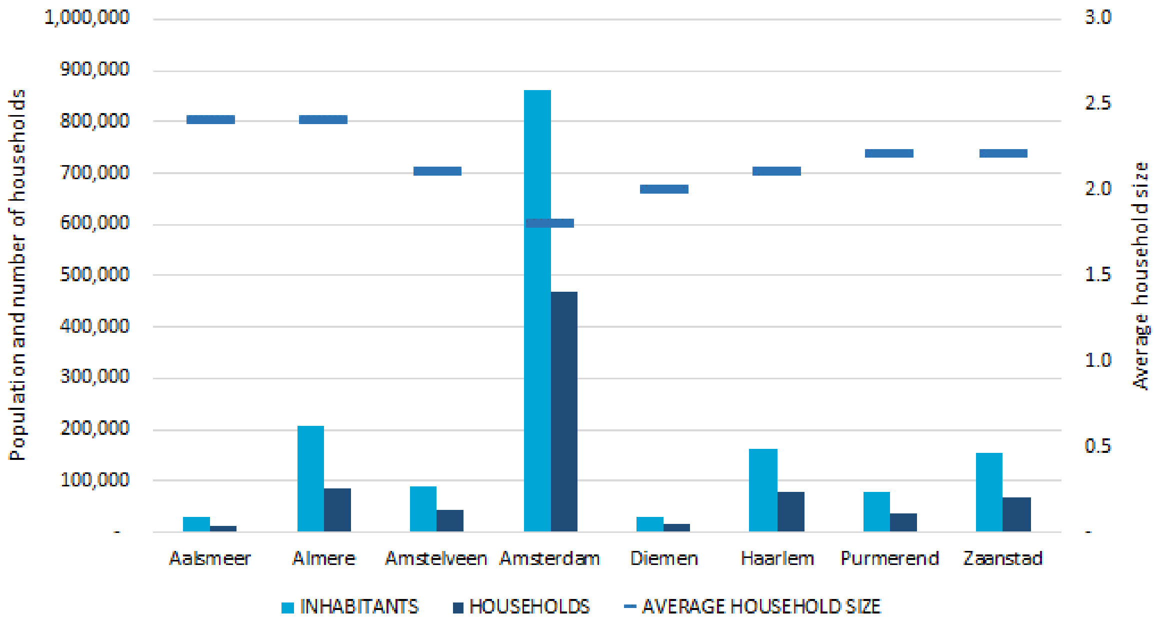


Figure 23 – Population, number of households and average household size for eight municipalities in the GA area (CBS, 2020)

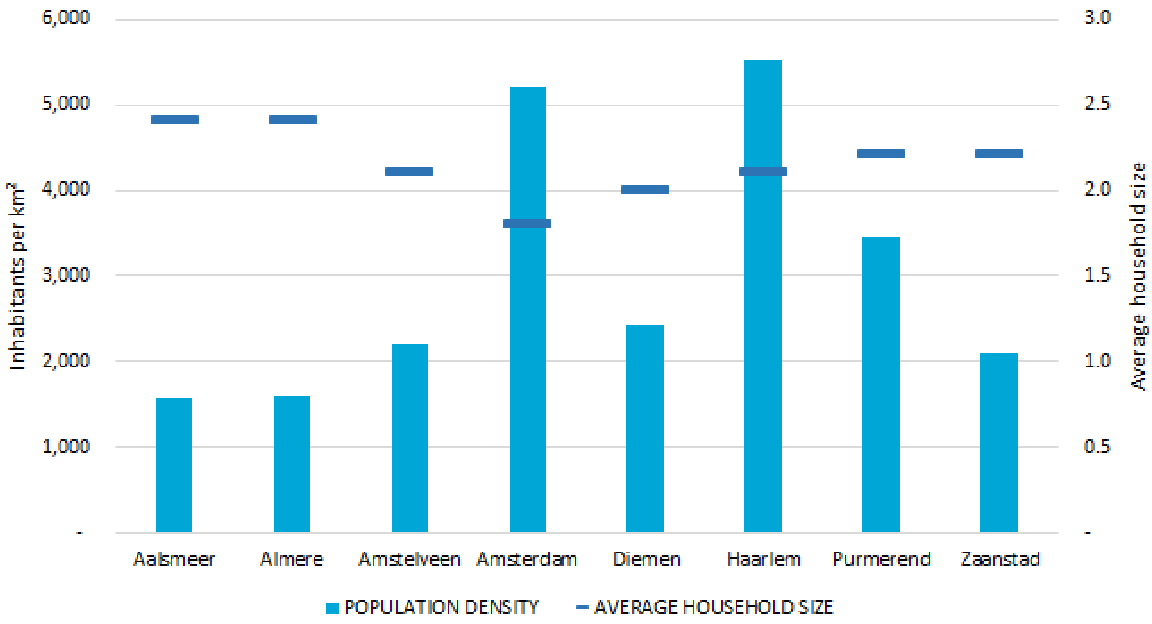


Figure 24 – Population density and average household size for eight municipalities in the GA area (CBS, 2020)

As discussed the two Amsterdam DH systems are characterised by relatively high building density, high shares of tenant- versus owner-occupancy and large numbers of buildings in HA-ownership. This corresponds to the fact that the vast majority of dwellings in Amsterdam are in a multi-family building; 88%. This is much higher than in all other municipalities and explains why the city of Amsterdam is a very interesting market for DH. Still, the market share for DH is – with only 10.8% of houses connected to DH in 2017 – much lower than in a city like Purmerend, with around 75% of houses being connected (CBS, 2020) (Segers, Van den Oever, Niessink, & Menkveld, 2019, p. 38), even though only 33% of dwellings is in a multi-family building (CBS, 2020).

The DH system in Purmerend is the only system of the four large DH systems in GA that is not connected to the others; the WPW and SE systems are currently being connected and the Almere system is supplied by and connected to the same CHP-plant in Diemen as the SE system. It is also the only system in which Vattenfall does not have 50% or 100% ownership. With 26,300 connections and 0.9 PJ of delivered heat this system is of comparable size as the WPW system in Amsterdam, as can be seen in Figure 25 (Segers, Van den Oever, Niessink, & Menkveld, 2019, p. 38). Only the number

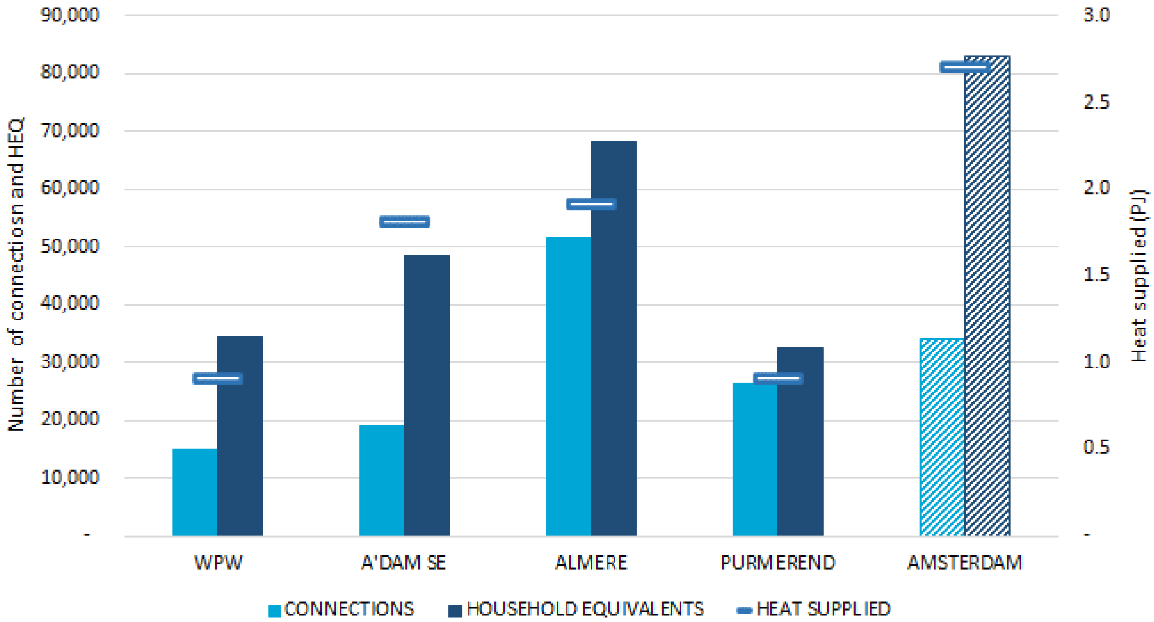


Figure 25 – Total number of connections, household equivalents (HEQ) and annual amount of heat supplied for the four large DH systems in the GA area (Segers, Van den Oever, Niessink, & Menkveld, 2019)

of connections in Purmerend is more than 75% higher than in the WPW system, which can probably be explained by the higher share of single-family houses in Purmerend (see Figure 26) and perhaps also by the share of connected commercial buildings, as the latter forms an important part of the consumers of WPW. Purmerend roughly 80,000 inhabitants, just over 40% of which are tenants and 35% in a HA-owned house (CBS, 2020). Purmerend is more densely populated than municipalities like Almere, Amstelveen or Zaanstad, which is an advantage and "makes up for" the share of single-family houses.

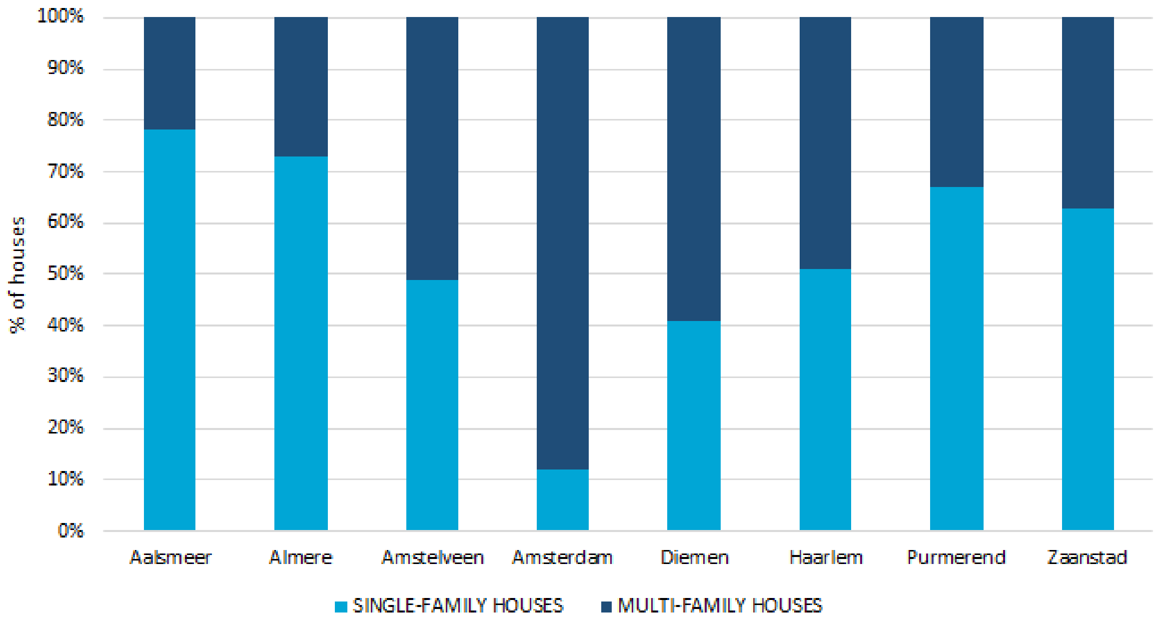


Figure 26 – Share of single- and multi-family houses for eight municipalities in the GA area (CBS, 2020)

As was explained, there is more information available on larger DH systems than there is for smaller and newer systems. The systems in Amsterdam, Almere and Purmerend are discussed and DH in Amstelveen and Diemen is both part of the Amsterdam SE system. The three municipalities that recently have established a DH system or are developing one are Aalsmeer, Haarlem and Zaanstad. Although the Aalsmeer system has, not long ago, been taken into operation, it still only has three customers. All customers are either for public services or commercial buildings; a swimming pool, an educational building and a horticulture company with greenhouses (Hamer, 2019). The DH systems in Haarlem and Zaanstad are mainly developed for residential buildings and aim to have many more connections than the system in Aalsmeer. Although these three systems – two in Haarlem and one in Zaanstad – still have to be (further) developed, they are all projected to have more than 1,000 connections; 1,130 for the Ramplaan-system in Haarlem (HIER verwarmt, 2018), up to 6,000 for Schalkwijk in Haarlem (Gemeente Haarlem, 2019) and 2,200 for the system in the east of Zaanstad (Stichting Warmtenetwerk, 2019). In Zaanstad a few educational buildings and healthcare institutions are also connected. The system in the Ramplaan-neighbourhood in Haarlem is planned to be a low temperature network and is therefore expected to have a lower total heat supply, compared to the larger systems in Amsterdam, Almere and Purmerend.

5.1.2.3. Regulatory framework

In the Netherlands DH has been a relatively small and immature market for years and probably still is. However, because the ambition of the Dutch national government is to reduce greenhouse gas emissions in 2030 with 49% compared to the level of 1990 and to have no houses connected to natural gas in 2050, the number of connections to DH is expected to rise significantly (Rijksoverheid, 2019, pp. 7, 37). Three subjects of regulation, legislation and policy regarding DH in the Netherlands will be discussed in this section;

- The Climate Agreement or *"Klimaatakkoord"* of the Dutch government, presented in 2019;
- The Heat Act or *"Warmtewet"*, which is currently under consultation and expected to come into force in 2022;
- Policies and targets of local governments, like the *"Routekaart Amsterdam Klimaatneutraal 2050"* of the municipality of Amsterdam.

Klimaatakkoord

On June 28th, 2019 the Third Rutte Cabinet presented the Dutch Climate Agreement, known as *Klimaatakkoord*. This agreement was the result of one and a half year of negotiations between (among others) ministries, municipalities and provinces, industry and agriculture, labour organisations, banks, housing associations, other societal organisations and NGO's (Klimaatberaad, 2018). The main goal of the Klimaatakkoord is to reduce greenhouse gas emissions in 2030 with 49% compared to the level of 1990 (Rijksoverheid, 2019, p. 7). In order to realise this goal measures are formulated for five sectors that each had their own negotiation 'table' with various stakeholders; *Built environment*, *Mobility*, *Industry*, *Agriculture and land-use* and *Electricity*. Measures that affect DH in the Netherlands were mainly formulated by the sector of the built environment.

The Klimaatakkoord emphasizes the need for a 'neighbourhood-oriented approach' to the energy transition in the built environment, in which citizens, building owners and the local government together search for the best solution to the shift away from the use of natural gas. Municipalities are in the lead in this process, but they will be supported by the knowledge programmes of the national government (Rijksoverheid, 2019, pp. 23-31). The Klimaatakkoord expects that for densely built neighbourhoods with a large share of stacked buildings and a building stock that is primarily pre-1995, DH is often the most appropriate solution to becoming independent from the natural gas grid (Rijksoverheid, 2019, pp. 15-16).

The Dutch state will also support homeowners (associations) through a new heat fund with public and private funding, from which they can secure 20-year loans of up to €25,000 with a 2%-interest (Nationaal Energiebespaarfonds, 2020). Furthermore, the government increases energy taxation on natural gas and decreases the energy tax for electricity, to stimulate investments in sustainability (Rijksoverheid, 2019, p. 23). The agreements states a growth of connections to DH should be realised, which should rise to 80,000 HEQ per year in 2025 up to 2030, leading to a total heat supply through DH that is expected to rise to 40 PJ in 2030. To contribute to the main goal of the Klimaatakkoord the DH companies have to lower average CO_2-emissions in their networks to 18,9 kg CO_2/GJ (Rijksoverheid, 2019, pp. 37-38). Lastly, the Klimaatakkoord states municipalities are responsible for drafting their own Heat Transition Vision – or *Transitievisie Warmte* – together with stakeholders, in which they explain the process of, collectively, making 1.5 million houses sustainable before 2030. Each municipality is obliged to have published their Transitievisie Warmte before the end of 2021 (Rijksoverheid, 2019, pp. 27-29).

Warmtewet

For decades there has not been any legislation regarding the DH sector specifically. It was not before 2003 when members of parliament submitted a bill regarding heat delivery to small consumers (Ten Hoopen & Hessels, 2003). Nevertheless, this bill only became law on January 1st, 2014, even when it was already passed by both houses of parliament in 2008 and 2009. After amendments and additions the new bill was submitted on 2011 and passed in 2013, coming into force as the *'Warmtewet'* in 2014 (Eerste Kamer der Staten-Generaal, 2013). However, it was already in 2015 when the new law was subject to debate because of difficulties in implementation and a planned evaluation was advanced (Kamp, Brief van de Minister van Economische Zaken, 2015). This was the unofficial start of the process for revision of the Warmtewet and preparations for a new law, the so-called *Warmtewet 2*. This new Warmtewet 2 is currently being heavily debated and going through a long process of public consultation. The new law is planned to come into force in 2022 (Wiebes, 2020).

The current Warmtewet focuses on a few things, like the rights of a DH-consumer regarding compensation for system failures, the obligation for a DH provider to offer smart metering, on what grounds heat delivery to a consumer can be terminated or the possibility for both consumer and provider to lodge an appeal at an arbitration committee in case of disputes (Rijksoverheid, 2013). However, the most important provision in the Warmtewet regards the DH price. Currently DH-prices are capped at a maximum price, which means DH companies cannot charge more than these prices. For every year these maximum prices, divided over cost components, are set by the Dutch Authority for Consumers and Markets (ACM), based on a reference to the average price a consumer would have to pay when he/she would generate the same amount of heat via a connection to the natural gas grid, which is – by far – the most common option in the Netherlands. This *"Niet Meer Dan Anders"* principle (NMDA) has been subject to increasing debate since it lacks a proper foundation for the link between heat and natural gas, especially as the natural gas prices is rising, partly because of tax increases by the Dutch government to stimulate alternative heating options (Kamp, 2017). The price regulation based on this NMDA-principle is one of the matters the new heat act, *Warmtewet 2*, will change.

The process towards a new heat act, the so-called Warmtewet 2, is subject to an even more heated debate. Without going into too much detail – especially as the new heat act is not finalized, let alone has come into force – the main aspects of the Warmtewet 2 are briefly discussed (Wiebes, 2020):

1. The municipality has a controlling role in defining so called 'heat plots'. For each of these plots, the municipality determines what will be the heating technology designated for the transition towards a sustainable heat provision. In case this is DH, the municipality assigns a DH company.
2. The DH company that is assigned to a heat plot is held responsible for the DH system as a whole; the entire value chain, from production to transmission/distribution to delivery. This way only one party needs to be addressed by governments or consumers, for example in case of malfunctioning.
    a. The heat act leaves room for other parties to fulfil some of the activities in the DH system. However, it specifically mentions heat production, construction, maintenance, billing and customers service and specifically does not mention distribution and/or ownership of the DH grid. This is one of the matters that is highly debated, as this is thought to prohibit the development of DH systems in collaboration between parties that fulfil the different roles (as discussed in section 3.1) and excludes the public network companies that are currently active in electricity and natural gas grids.
3. An opt-out system for consumer connection to DH. If a building owner does not want to be connected to the DH system, a connection may be refused, as long as certain criteria are met and this is done well in advance.
4. The Dutch state can assign a DH transmission system operator in the exceptional case that access to large scale, sustainable heat sources are available and require a coordinated approach and investments. This is related to the assignment of Gasunie, the Dutch TSO for natural gas, as a DH transmission system operator in the province of Zuid Holland (Rijksoverheid, 2019).
5. There will be a phased transition to a different price regulation scheme, which will be based more on actual costs than the current NMDA principle. This should ensure recuperation of investments by DH companies, plus a 'reasonable' profit. However, decisions on details of this price regulation will only be around 2030.
6. There will be an obligatory minimal trajectory for increasing sustainability of the DH system. Transparency on sustainability will be enhanced and surplus heat will be subject to a 'right to collect' for DH companies. DH companies should demonstrate they are able to ensure reliability and sustainability of the heat supply.

Local policies and targets

Besides the national legislation on DH and the government's Climate Agreement, local authorities also draft their own policies and set targets for the energy transition in general and, sometimes, for DH in particular. For the municipalities within the GA area a few of these policies will be discussed.

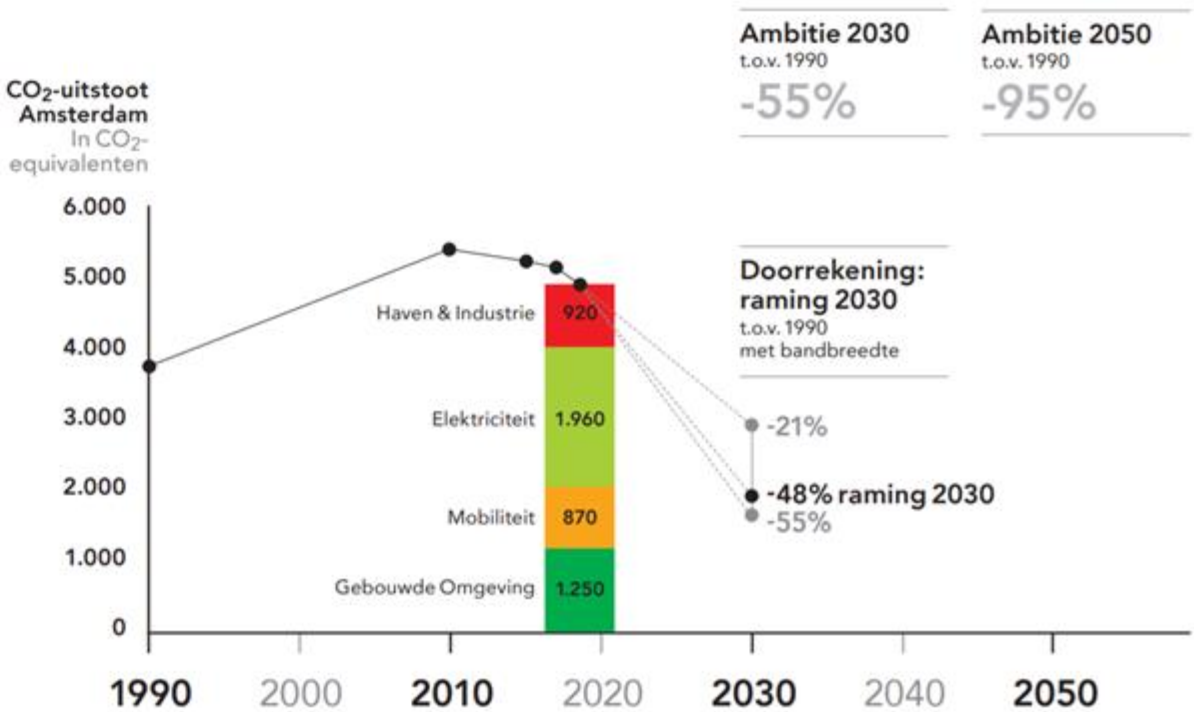


Figure 27 – Ambitions of the municipality of Amsterdam for reducing CO2e-emissions (Gemeente Amsterdam, 2020, p. 7)

The municipality of Amsterdam has its own 'climate agreement' since March 2020. Of the total CO_2e-emissions in Amsterdam 25% can be allocated to the built environment; 14%, 7% and 4% for residential, commercial and public buildings, respectively. As shown in Figure 27, Amsterdam wants to cut these emissions – of currently about 5,000 kilotonne CO_2e – with 55% for 2030, compared to the level in 1990, which was under 4,000 kilotonne CO_2e and even with 95% for 2050 (Gemeente Amsterdam, 2020, pp. 6-7). The built environment is one of the four transition pathways the municipality formulated; this pathway is mainly focused on the transition away from natural gas for the existing building stock and construction of new, energy neutral buildings, as the majority of the emissions in the built environment is from the use of natural gas and heating (Gemeente Amsterdam, 2020, p. 35). The municipality aims to have the whole built environment free from natural gas in 2040; this regards 650,000 HEQ. In 2019, 91,000 HEQ were free from natural gas, in 2030 this number should be increased to 260,000, the last 390,000 (!) should be realised between 2030 and 2040 (Gemeente Amsterdam, 2020, p. 62).

Connecting houses to DH will be an important part of realising this ambition. The municipality investigates the possibilities, together with housing associations and WPW and Vattenfall, to connect 110,000 houses to the two existing DH systems (Gemeente Amsterdam, 2020, p. 64). Amsterdam was also the first Dutch municipality to publish their *Transitievisie Warmte*, the policy document that all Dutch municipalities are obliged to publish before the end of 2021, as briefly discussed above, under *Klimaatakkoord* (section 5.1.2.3). When looking at this document, it becomes quite clear DH is assigned an important role in the energy transition. The municipality estimates that an additional 250,000 HEQ will be connected to a high-temperature (70°C) DH system in 2040, besides the 102,000 HEQ that are already connected, as illustrated in Figure 28. An additional 85,000 HEQ will be connected to a mid- or low-temperature system of 40°C (Geldhof, Nieuwenhuis, Oudejans, & Smoor, 2020, p. 19). Furthermore, roughly 150,000 HEQ will be using a so called local "bronnet", which could be translated freely as a "source network" or "network as a source", as the system uses a small, local DH grid on low temperatures – often between 10°C and 20°C – as source for (collective) heat pumps. The advantage of this type of system, which could be fed by e.g. surface water, a sewage or an underground heat/cold storage, is that it can also provide cooling. Even if these 'bronnetten' are not included in the calculation, DH systems are still expected to supply 54% of all HEQ in the municipality of Amsterdam in 2040.

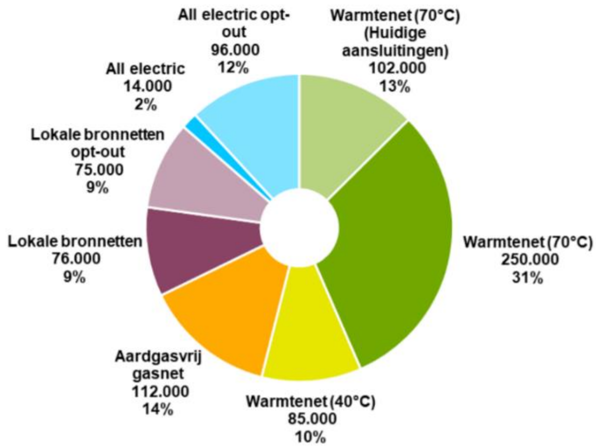


Figure 28 – Share of and number of HEQ per heating technology in Amsterdam in 2040 (Geldhof, Nieuwenhuis, Oudejans, & Smoor, 2020, p. 19)

Of the other municipalities in the GA area most are still working on their vision on the heat transition and therefore have not yet published a "Transitievisie Warmte". Luckily, they still have one and a half year to do this. Only the municipality of Almere has published such a vision. In fact, this was done in 2017 already. Almere formulates two main solutions; 1) electrification of the heat demand on building level and 2) connecting to a DH system (Smoor, 2017, p. 5). For the latter the municipality will probably count on the current DH system of Vattenfall. Other municipalities are currently working on their vision, like Purmerend (DWA, 2020) and Haarlem (Schilling, Naber, & Schepers, 2019).

5.1.2.4. Economical parameters

The DH systems in the GA area are, in most cases, not connected and therefore each have their own business case, ownership structure and physical characteristics. However, the same national legislation applies to all systems; price regulation, taxation and (national) subsidies are equal for the systems in GA. Factors like heat demand, availability of sources and population density are different. This section will elaborate on three subjects; prices for DH, heat demand and taxes and subsidies.

District heating price

The price a consumer pays to his DH provider differs per year, per heat provider and sometimes, with the same provider, even per region. However, all DH prices are subject to the provisions in the current heat act regarding the NMDA price cap – at least until the new heat act, *Warmtewet 2*, comes into force around 2022. When looking at the Amsterdam DH system, there are two DH companies: Vattenfall in the southeast and Westpoort Warmte (WPW) in the northwest. Although the WPW system is in shared ownership between AEB (owned by the municipality of Amsterdam) and Vattenfall, the consumers are direct clients of Vattenfall (Van Zanten, 2019). In both the WPW and

SE systems, consumers get their heating bill from Vattenfall and in both systems the same tariffs are applied. In fact, in the system of Almere, where Vattenfall is also the monopolistic, fully integrated DH company, the same tariffs as in Amsterdam are applied (Vattenfall, 2020). However, this does not have to be the case, as is proven in Vattenfall's DH system in Rotterdam. For example, when looking at consumers that have a DH-connection with a capacity of under 50 kW, the tariffs for the fixed costs are different between Rotterdam and Amsterdam, as is shown in Table 6. For the variable part of the DH price – the tariff for per consumed GJ – prices are equal for all Vattenfall DH systems in the Netherlands: with € 25.90 this fee is just under the ACM maximum tariff of € 26.06.

COST COMPONENTS	**AMSTERDAM**		**ROTTERDAM**		**PURMEREND**		**ACM MAXIMUM**	
DH company	*Vattenfall*		*Vattenfall*		*SVP*		*ACM*	
Connection size	*< 50 kW*	*50 - 100 kW*	*< 50 kW*	*50 - 100 kW*	*< 50 kW*	*50 - 100 kW*	*< 50 kW*	*50 - 100 kW*
VARIABLE COSTS								
Price per GJ	€ 25.90	€ 25.90	€ 25.90	€ 25.90	€ 26.06	€ 26.06	€ 26.06	€ 26.06
With 35 GJ	*€ 906.50*	*€ 906.50*	*€ 906.50*	*€ 906.50*	*€ 912.10*	*€ 912.10*	*€ 912.10*	*€ 912.10*
Discount	*€ -*	*€ -*	*€ -*	*€ -*	*€ -33.00*	*€ -33.00*	*n.a.*	*n.a.*
SUBTOTAL VARIABLE	**€ 906.50**	**€ 906.50**	**€ 906.50**	**€ 906.50**	**€ 879.10**	**€ 879.10**	**€ 912.10**	**€ 912.10**
FIXED COSTS								
Fixed fee	€ 469.17	€ 469.17	€ 201.55	€ 469.17	€ 469.17	€ 469.17	€ 469.17	€ 469.17
Metering	€ 26.63	€ 26.63	€ 16.36	€ 26.63	€ 26.63	€ 26.63	€ 26.63	€ 26.63
Delivery set	€ 126.19	€ 241.14	€ 114.44	€ 241.14	€ 126.19	€ 126.19	€ 126.19	€ 241.14
Discount	*€ -146.38*	*€ -146.38*	*€ -*	*€ -146.38*	*€ -85.00*	*€ -85.00*	*n.a.*	*n.a.*
SUBTOTAL FIXED	**€ 475.61**	**€ 590.56**	**€ 332.35**	**€ 590.56**	**€ 536.99**	**€ 536.99**	**€ 621.99**	**€ 736.94**
TOTAL	**€ 1,382.11**	**€ 1,497.06**	**€ 1,238.85**	**€ 1,497.06**	**€ 1,416.09**	**€ 1,416.09**	**€ 1,534.09**	**€ 1,649.04**

Table 6 – Tariffs for DH in 2020, both for variable and fixed costs, in three selected systems in the Netherlands (own illustration, based on (Vattenfall, 2020) (Stadsverwarming Purmerend, 2020))

Within the Amsterdam and Almere DH systems, all tariffs are equal. However, in the city of Purmerend, the other municipality with a large DH system of over 200 TJ annually, tariffs are different. The local DH company SVP for example charges the maximum tariff for each GJ consumed, but does provide a fixed discount on the annual heat bill (SVP, 2020). Furthermore, SVP does not differentiate between small consumers, as can be seen in Table 6: both connections under 50 kW and between 50 kW and 100 kW pay the same tariffs, in contrast to consumers in the DH systems of Vattenfall. This leads to the fact that if a consumer has a connection with a capacity under 50 kW, he/she pays less in a DH system of Vattenfall than in Purmerend, where the opposite is true for connections between 50 kW - 100 kW.

Tariffs in other DH systems in GA can also be different. The DH companies in Aalsmeer, Haarlem and Zaanstad are different and e.g. their system dimensions, operating temperatures, business cases and consumer types are too. As long as a DH company comply with the maximum tariffs that are set by law and monitored by the ACM, they can charge whatever they want. This might change when the new heat act comes into force, as this is expected to base DH tariffs more on actual costs and a 'reasonable' profit (Wiebes, 2020).

Heat demand and density

The heat demand density (HDD) of a DH system is important, for example to its operational efficiency or financial business case, as explained in section 3.2.1. Areas with a higher HDD are thus more likely to be viable and reasonable, although this of course depends on more than this factor. Looking at a map of HDD in the GA area in Figure 29, it quickly becomes clear there are quite a few urban areas with high HDD, of which the city of Amsterdam is the largest and 'most dense' (Heat Roadmap Europe, 2020). Several of the cities with a high heat demand and HDD already have one or more DH system in place. Still, relatively large municipalities like Haarlem and Zaanstad only have a very small DH that is even still to be developed.

Furthermore, even in a very large city like Amsterdam DH only has a market share of around 13% of all HEQ (Geldhof, Nieuwenhuis, Oudejans, & Smoor, 2020, p. 19). The WPW and SE DH systems do not cover the entire city – and probably will not ever – but the connection density in the areas in which a system is operational may also not be 100%. Densification of connections to DH could therefore considered of equal importance to the business case of the systems as expanding the system to new areas. And when expanding to new areas, connection density is at the core of realising this expansion. Especially as Dutch consumers cannot be forced to connect to DH, at least not as easily as in Denmark,

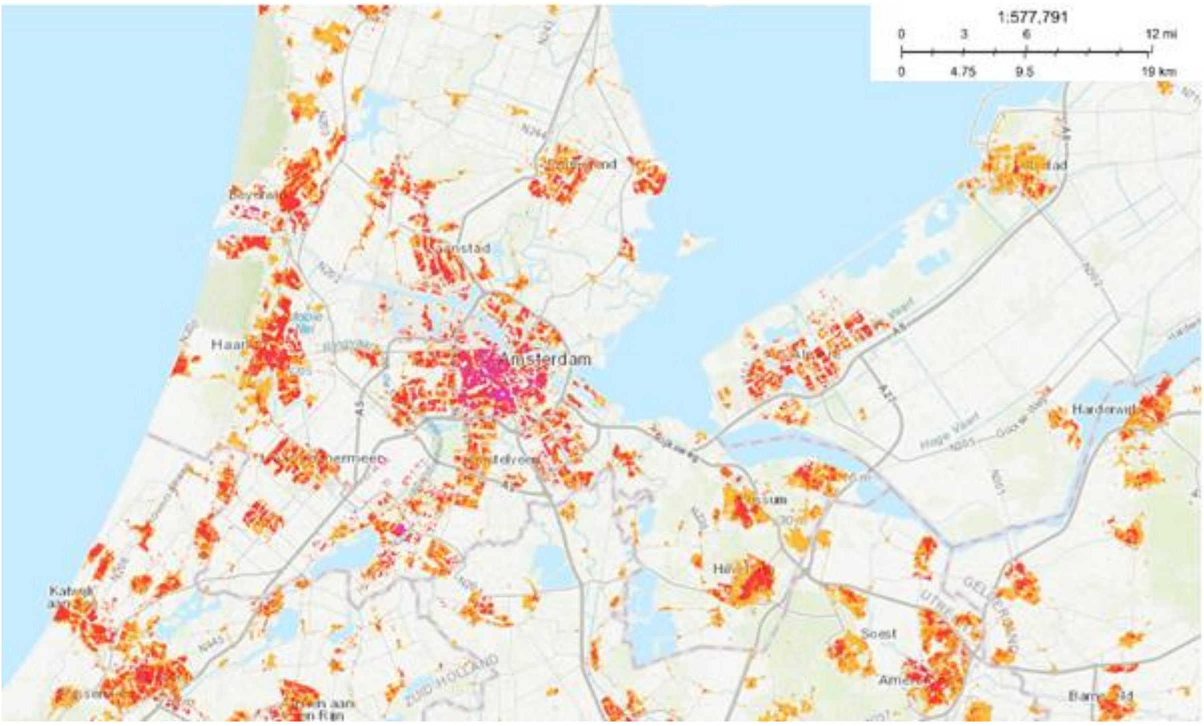


Figure 29 – Heat demand densities (2015) for Greater Amsterdam area. Areas in purple are >300 TJ/km², in red 120-300 TJ/km² and in orange 50-120 TJ/km². Source: (Heat Roadmap Europe, 2020)

it becomes one of the most important risks that a DH company needs to mitigate; how to realise a connection density that is high enough for a viable business case?

Taxes and subsidies

As the DH sector in the Netherlands has, at least until now, not been that large and mature, there are very few direct fiscal policies and/or subsidies for DH. However, the role of DH in the Dutch heating sector is changing. Besides, there already are quite a few taxes and subsidies that indirectly affect DH systems. In this section a few currently existing taxes and subsidies will be briefly discussed.

The most important tax that currently affects DH is the energy taxation on natural gas. As long as the DH price cap based on the NMDA principle is effective, this price cap is subject to both a fluctuating and unpredictable market price for natural gas and a steadily rising energy taxation on natural gas. Especially the latter is a reason for irritation and impatience, as it undermines social support for DH systems, when this tax is in fact raised in order to stimulate the transition away from natural gas. This is the main reason for abandoning this mechanism for price regulation in the new heat act. On the other hand, DH systems that use electricity – for example for heat pumps in LT systems or in electric boilers, like Vattenfall is planning in the SE system (Vattenfall, 2020) – are positively affected by a lowering energy taxation on electricity (Rijksoverheid, 2019, p. 23). One last important fiscal policy is a tax deduction for investments that realise a significant reduction in energy use, the so called *Energie-investeringsaftrek* or EIA, with a total budget of € 147 million for 2020 (Rijksdienst voor Ondernemend Nederland, 2020).

Besides taxation there also are a few subsidy schemes and loan opportunities with favourable conditions. One important subsidy regarding heat production is the so called SDE+ scheme, which is an abbreviation of *Stimulering Duurzame Energieproductie*, focusing on subsidising renewable energy production. From January 1st, 2020 this scheme is replaced by the SDE++, which is a broader subsidy that also includes measures that reduce energy consumption (PBL, 2020). Subsidies specifically used for investments in the development of DH grids are not available on a national level, although there are a few European Union funds that for example offer subsidies and loans for DH-grid construction (Schilling, Nikdel, & De Boer, 2018, p. 31).

Housing associations and private landlords that want to switch from natural gas to a DH grid are supported by a € 200 million subsidy scheme, estimated to be helping 55,000 dwellings with a maximum payment of € 5,000 (Rijksoverheid, 2020). Furthermore, individual homeowners and homeowners associations are supported by a new heat fund of the Dutch government. They can secure loans with a of 15 years with a 1.9% to 2.1% interest or 20 years with a 2% to 2.2%

interest and a size of up to €25,000 (Nationaal Energiebespaarfonds, 2020). Housing associations can apply for various subsidy schemes that focus on building retrofits (Schilling, Nikdel, & De Boer, 2018, p. 31).

5.1.2.5. Future challenges

Like the Greater Copenhagen DH system, there are quite a few challenges ahead for the DH systems in the GA area. In this section the many challenges that were discussed in stakeholder and expert interviews are considered, the most striking or important challenges are briefly described below.

The following challenges were mentioned by stakeholders and/or experts, for the Netherlands in general and for the Greater Amsterdam DH systems specifically:

- There currently is high uncertainty regarding the (long-term) regulation of the Dutch DH sector, as the national government is reviewing the existing *Warmtewet* and working on a new law that should regulate and organise the DH sector;
- In the Netherlands DH is competing with cheap natural gas supplies – at least that has been the case over the last decades – and a very mature and well functioning natural gas grid. This makes it hard for new DH developments to 'win' from the existing alternative;
- There seems to be a lack of (operational) experience on DH, besides with a handful of large energy companies. This is not only a problem for the DH companies itself, but also for municipalities that need to oversee and coordinate the heat planning process, but lack knowledge and experience. Moreover, in the procurement procedure one of the prerequisites is often to have a minimum level of experience for the tendering companies, which leads to exclusion of new entrants, like citizen cooperatives (Marselis & Hisschemöller, 2018, pp. 40-41);
- Societal support for DH in the Netherlands is fragile, as people do not know or understand the technology, because consumers are or feel not included and because there is a heated debate about both the costs of DH and the environmental benefits, especially with HT systems on CHP or waste incineration;
- Societal support for biomass is low and volatile. Currently there is a very heated debate about the use of biomass for electricity and heat production, both in society and in local and national politics. Opinions are shifting, which is leading to fast erosion of the support for biomass and calls to cease subsidising biomass for electricity and heat production;
- The transition to "green" or "sustainable" DH is sometimes considered (too) expensive. As mentioned above support for the use of biomass in DH is decreasing rapidly and renewable alternatives are often not adequate, for example because of high costs or technological deficiency;
- The absence of an obligation to connect houses to DH sometimes results in a load risk ("vollooprisico" in Dutch) that is considered too high, as this often leads to higher financing costs and an overall insecure business case for the DH company;
- There is a possibility for the abuse of monopoly-power in integrated DH systems. Many Dutch systems are – like the GA systems – owned and operated by a vertically integrated DH company and in several cases there are complaints about not being able to disconnect from the DH grid or about prices that are considered too high and untransparent;
- There are too few parties on the DH market to reach effective competition on tenders for new DH systems;
- Many DH systems are dependent on only one or very few heat sources, as is also the case for the GA systems;
- The current building stock in Amsterdam and neighbouring municipalities is in many cases not ready for lowering the systems' forward temperature, as the quality of insulation and the heat delivery system is often insufficient for low temperatures;
- The large production plants create a lock-in because of their high investment costs and long-term contracts;
- Seasonal differences in heat demand and -production have a negative influence on the business case for third-party access for producers. This could be mitigated by creating seasonal storage capacity, but that is still (considered) too expensive in many cases;
- Over the last year there have been major financial and organisational problems at the waste incineration company of AEB. This resulted in the municipality of Amsterdam wanting to sell (a part of) their share in AEB, but only after AEB's 50% share in WPW is sold by AEB to a public party. This crisis creates high uncertainty and the possibility that the WPW system will be fully owned by the private company of Vattenfall, resulting in an even stronger monopoly situation;

5.2. Cross-case overview

This section provides a brief overview of the two cases on a number of elements that were discussed in section 5.1. The overview is given in Table 7, below. A few notable elements will be discussed briefly. The following chapters – 6, 7 and 8 – will then continue with a cross-case analysis on three subjects, as was discussed in section 2.5.

ELEMENTS	COPENHAGEN	AMSTERDAM
HISTORICAL DEVELOPMENT		
First DH developments	1903	1990's
Main period of expansion	1970's - 1980's	1990's – today
CURRENT SYSTEM		
Size		
Number of connections	Roughly 500,000	Roughly 112,000
Annual heat consumption	32 PJ	5.5 PJ
Production		
Ownership	Private & public	Private & public
Heat sources	Biomass, waste & natural gas	Waste & natural gas
Total capacity	Roughly 4,300 MWth	Roughly 1,400 MWth
Transmission		
Ownership	Public	Private & public
Unbundling	Unbundled	Fully integrated (DSO, prod. & prov.)
Distribution		
Ownership	Public & cooperative	Private & public
Unbundling	Integrated with provider	Fully integrated (DSO, prod. & prov.)
Consumption		
Building types	Multi-dwelling houses (50%), office buildings (20%)	Multi-dwelling houses, commercial buildings and single-family houses
Residential/non-residential	Mainly residential (63.1%)	Unclear
Ownership & tenants/owners	Individual ownership (± 40%), housing associations and -cooperatives (± 40%) and tenants (± 60%)	Individual ownership (± 50%), housing associations (± 35%) and tenants (60%)
Market share for DH	74.3%	Roughly between 15% and 20%
REGULATION		
Climate & energy policy, targets	Being CO_2e-neutral in 2025	Reduce CO_2e with 55% in 2030 (from 1990) and 95% in 2050
Tariff regulation	Cost-based tariff entire value chain	Cap on end-user price
Obligatory connection	Widely used, but phased out	Only possible for new buildings
Heat planning	Top-down, mainly by municipality	Top-down, mainly by municipality
ECONOMICS		
DH price	Roughly €1,725 per year, with ± 65 GJ/a (national average for 2019)	Between €1,400 - €1,500 per year, with ± 35 GJ/a (2020)
Heat demand density	Large areas (urban core) with >300 TJ/km², suburbs <120 TJ/km²	Amsterdam center >300 TJ/km², suburbs and other cities vary: 300-50 TJ/km²
Taxes	Tax exemptions for biomass, no tax on heat consumption	Mainly indirect fuel taxes
Subsidies	Subsidy for biomass in CHP	Mainly for renewable production and energy efficiency measures

Table 7 – Overview of the cases of the Greater Copenhagen and Greater Amsterdam DH systems, on selected elements in the categories of historical development, the current DH system, the regulatory framework and economic parameters

Most prominent is the difference in size of the DH systems in both cases. The GC system is roughly 6 times as big as the GA system, even more when only the two system parts in the municipality of Amsterdam are counted. Less easy to notice, but at least as important are differences in ownership structure of the different parts of the DH value chain. In GC roughly half of the production capacity is privately-owned, but the rest of the value chain is either owned by municipal companies or cooperatives. In contrast, the GA system is mostly privately-owned. Also, in GA the different roles in the system are largely integrated into one DH company, where Vattenfall is the vertically integrated monopolist in the SE system and only in the WPW system there is only some 'unbundling', as the AEB waste incinerator is solely owned by the municipality of Amsterdam. In the GC system, again, this is organised somewhat differently, as the main production facilities are partly unbundled, but – most importantly – an independent organisation is responsible for the dispatch of production and transmission companies operate independently from companies that distribution and provide heat to consumers. A third important difference is the tariff regulation: in GC this is entirely cost-based, in GA there only is a price cap for end-user prices, although the latter is subject to changing legislation. Still, the consumer price for DH seems to be lower in the GA system, compared to the GC DH price (although the number in in Table 7 is a national average). However, this is not directly comparable, as it is not adjusted for purchasing power and household income.

In both cases the majority of consumers is residential and lives in multi-dwelling houses, although single-family houses and commercial buildings are common too. Most of the residential consumers are tenants, of which many rent from a housing association. The cases also show similarities on production: both are mainly supplied by CHP-plants and waste incinerators and both systems suffer from a lock-in by these facilities, due to high investments, a lack of alternatives and high forward temperatures. However, the CHP-plants in Copenhagen are considered largely 'sustainable', as they are primarily biomass-fired, in contrast to the higher dependency on natural gas in (Greater) Amsterdam, with only a biomass boiler in the city of Purmerend.

As the GC system is much older and already had a period of rapid expansion in the 1970's and 1980's through strong central heat planning and clear obligations to connect, the market share is very high with roughly 75%. In dense cities like Copenhagen and Frederiksberg this is even close to 100%. In the GA systems the development only occurred from the 1990's and is expected to go through a more rapid expansion in the coming years. This is one of the most important ways the city of Amsterdam aims to reach its climate goals of reducing CO2e-emissions with 55% in 2030 and 95% in 2050, compared to 1990 levels. The municipality of Copenhagen is even much more ambitious, as they intend to be carbon neutral in 2025, in which DH plays a very important role.

6

STAKEHOLDER ANALYSIS

Stakeholder types, their interests and varying influence

Vattenfall's *Diemencentrale* CHP-plant, Diemen

Like any large and complex system in an urban area, district heating systems often affect many different stakeholders. However, this does not necessarily mean that all of these stakeholders can influence the way this system is designed. Besides, varying stakeholders sometimes have very different interests when it comes to DH systems. One stakeholder might simply want the lowest energy bill as possible, where another might think a sustainable heat source is crucial, considering the energy transition many cities are in. One stakeholder might want to make a nice profit from its activities and another is just interested in not having to worry about heating in general.

Knowledge of the various stakeholders and their different interests and influence is important, both to understand the complexity of the heat planning process and to be able to collectively work towards a suitable DH system design for the urban area in which this is appropriate. This chapter will provide an overview of common stakeholder types, their main characteristics, the interests they generally have and the way they can or cannot influence the system design. In doing so, this chapter answers the first part of the second sub-question.

SQ2	What are the characteristics, interests and influence of the main stakeholders in a district heating system in a metropolitan area and what are the resulting requirements towards the system?

This chapter consists of three sections. In section 6.1 ten stakeholder types are identified and described. In section 6.2 the interests and influence of these stakeholder types is discussed. Section 6.3 concludes this chapter by answering the first part of the second sub-question.

6.1. Stakeholder types and characteristics

Although stakeholders in DH systems might individually differ quite a lot, they could be described along a certain typology. This section will formulate several stakeholder types and, for each of these types, will describe their main characteristics. This typology and the characteristics are mainly based on the case studies of the DH systems in the Greater Copenhagen and Greater Amsterdam areas. For every stakeholder type at least the following properties are described:

- Role: *which role(s) does the stakeholder type generally fulfil in a DH system?*
- Activities: *what DH-related activities does the stakeholder type perform?*
- Ownership: *what ownership structures may exist for this stakeholder type?*

Note that the role(s) a stakeholder fulfils are not the same as the stakeholder type itself. Furthermore, roles and activities are considered different: activities of a national government may be to draft laws and regulations, but the role it fulfils is simply the role of *Government*, as described in section 3.1. Another example: a housing association (HA) might fulfil the role of *Consumer* in a DH system. This is because in many cases the HA has a contract with the provider of DH, although the tenant is the end-user of this heat. The HA is not the end-user as the HA itself does not consume heat, besides heat consumption for heating the housing association's offices, when the organisation itself consumes heat and is thus both consumer and end-user. The differences between stakeholder types, their roles and their activities will become more explicit and clear in the descriptions below.

Municipality

In every DH system the local municipality is a stakeholder, as every system is established within the area of at least one municipality. The municipality is a public organisation that directly represents the citizens on its territory. The DH-related activities of a municipality differ per country and even within a country. However, municipalities, in their role of (local) government, are mainly active in urban and energy planning, policymaking and facilitating, e.g. through issuing permits or offering support to citizens and organisations. Urban planning and energy planning are often closely related, especially in urban expansion projects where new residential and/or buildings are combined with a new energy system and various collective energy technologies are considered. Municipal policymaking focuses on topics like urban energy systems, local climate policies and the execution of the transition away from fossil fuels, towards renewable energy. Depending on the national legislative framework, the municipality often also has the responsibility to assess permit applications for energy projects and thus the power to issue or reject these permits for projects for or related to DH.

Municipalities quite frequently also participate actively in a DH system. However, this is not the 'standard' and there are, to my knowledge, no (Western) countries where municipalities have the obligation to establish a DH company. If a municipality participates in DH, it can for example do this through (shared) ownership of an integrated DH company or by producing heat in a municipally-owned plant and feeding this in to the system of another DH company. However, this would be considered a different stakeholder, like discussed in sections 0 or 0, which simply is publicly owned.

National government

National governments consist of many different departments, agencies and other sub-organisations. Not all of these are involved in energy in general or DH in particular. In many European countries there often are one or two ministries that consider DH as part of their portfolio of responsibilities; in some countries this is a ministry for energy, in some for economic affairs, for domestic affairs, the built environment, energy transition, sustainable development or anything related. Besides the main government ministries or departments, there frequently are special government agencies that are assigned the task to regulate and/or supervise the DH sector and the companies that are active in it. These may vary from market regulators to consumer appeal boards and anything in between. These agencies usually fall under the responsibility of a ministry or department.

Where municipalities draft policies that are focused on a local and regional scale, national governments have – of course – a wider scope. However, national governments often include local authorities in their process of policymaking, as these generally have to be appropriate and feasible for all different regions. Furthermore, the national government is responsible for drawing up and amending laws that relate to the energy and DH sectors, where lower governments only execute and enforce these laws. The national government is the most important tax authority and establishes tax regimes that can stimulate or discourage certain developments, like lower taxes on electricity or biomass or higher taxes on natural gas for example.

In principle national governments can also participate in companies that are active in DH, although this is less common than it is for municipalities. This is mainly due to the fact that DH systems operate on a regional scale, where for natural gas and electricity grids this is on a (inter-) national scale. State-owned CHP-plants and investments in DH transmission grids are slightly more common, activities in distribution and delivery only through large (multi-) national energy companies.

Housing association

Most DH systems are established in densely populated urban areas, especially the large scale systems. Housing associations (HA's) are often very present in dense urban areas; they generally build relatively small houses and the share of houses that are owned by HA's is often higher in the large cities, compared to the average of a country (Statistics Denmark, 2020) (CBS, 2020). Given that HA are an important stakeholder in many DH areas, it becomes important to understand what role they actually fulfil. HA are organisations that let dwellings to tenants, often in a 'social' construction in which the rental fee is lower than the market price. They are often legally organised as foundations or associations and are heavily regulated in many countries. In most cases they are also supported by national and/or local governments through beneficial fiscal schemes, subsidies or legislative exceptions. They are neither privately, publicly nor cooperatively owned as they are foundations or associations. However, given the strong government influence, considering them to be public organisations would be best suitable.

HA's fulfil the role of consumer in a DH system. This is because they act as one large consumer; they often negotiate customized DH-tariffs as represent large numbers of end-users and they regularly have one connection per building, although the building houses many dwellings. Besides, it is generally not possible for one single tenant in a HA-owned apartment building to switch to another heat technology, heat provider or to negotiate his/her own DH-contract. This makes that the HA functions as the consumer of the DH company; it is the party that signs the contract.

Individual consumer

The individual consumer – both residential and non-residential – is a consumer that represents only one organisation or household and has its own heat contract with and bill from the DH company. Naturally this includes citizens that, alone or together, live in a dwelling and form one household. It does not necessarily matter if this private, residential consumer also owns the house or apartment he/she lives in; both homeowners and tenants can be individual consumers, as long as they have their own heat contract. However, it may be the case that the individual consumer cannot choose to disconnect from the DH system, even when it has its own DH contract and an individual bill. This could be so when it does not own the building. In this case, the building owner is not the user of the building and thus not the consumer of DH, but it is in charge of making decisions about the technology through which the building is heated; whether to dis-/connect from/to a DH system is, in most cases, up to the building owner, not the individual consumer. The building owner as a stakeholder is discussed further in section 0.

Commercial or industrial companies and public organisations can also be an individual DH consumer. As DH is also used to heat offices, factories, schools, swimming pools or greenhouses, there are lots of individual non-residential consumers. These organisations are considered individual consumers when they have an individual heat contract with the DH company. This could be the case for an industrial building of a family-owned company, or for a horticulture company with greenhouses. However, it might also be the case that an office building is used by ten different organisations and is owned by a real estate investor. In this case the ten individual organisations might not have an individual heat contract with the DH company, as the whole building is heated on one contract. Then these ten organisations are not individual consumers, as there is only one heat contract which is signed by the building owner and thus the latter is considered the individual DH consumer, although it is not the end-user.

Building owner

Firstly, when discussing the building owner as a stakeholder in the DH system, it is important to note that organisations only fall in this category if they are the owner of a building, but not the user of that building and thus not the DH consumer, given that the building is connected to a DH system. Although a building owner is not a stakeholder that has a very direct relation to the DH system, it may not be forgotten and is of greater importance than one might think. As the building owner has the legal control over its properties, this stakeholder is of vital importance to the viability of a DH system's business case, given the fact that a building's owner decides whether or not it is connected to the system.

Building owners exist in various forms; the owner of a row of houses in an old city centre, of an apartment block in the suburbs, of a shopping mall or of an office building can all be classified as the building owner. However, organisations or individuals that both own and use a building that is connected to DH are always considered a consumer. So a commercial company that owns their own office building, a small industrial company with their own factory or a private homeowner are all examples of consumers, not building owners. Different people and organisations can be a building owner, varying from a person that inherited a house and now rents it out, to a real estate investor that owns a shopping mall with many stores that are leased to small shopkeepers. The only special case is the housing association, as discussed in section 0: these are organisations that own many buildings and do not use those buildings themselves. Still, they are not considered to be 'regular' building owners, as they are extraordinary organisations and have a great and specific role in many DH systems.

The responsibility of a building owner is not only to decide about connecting to a DH system or not. Other important parts of the building owner's impact regard decisions about building renovations, as interventions like upgrading insulation have an influence on both the forward and return temperature of a DH system, or taking measures that deal with energy consumption, like demand-side management technologies. Because of this impact building owners are an important party to DH companies.

Third-party producer

In many DH systems, both small and large, there are third-party heat producers active. Naturally every DH system needs some kind of heat production, generation or extraction and thus there is a party that fulfils the role of producer in every system. However, the third-party producer, as a stakeholder type, is characterised as a party that only produces heat, but is not active in any other role within the DH system than in the role of producer.

A third-party producer can generate heat through any kind of production technology. Whether it owns a large CHP-plant, a small biomass boiler, a geothermal well or generates surplus heat through an industrial process does not matter, as long as it produces heat that is fed into a DH system that is not owned or operated by the third-party producer. Also, whether heat generation is the core business for the organisation or it is simply subordinate to the main service or production process is also not important. Third-party producers can be active in all kinds of sectors; a datacentre that supplies surplus heat from its servers, a waste company that produces both electricity and heat through incineration, a supermarket that supplies surplus heat from their cooling equipment, a sewage treatment plant that treats wastewater or an energy company with a very large CHP-plant on natural gas. These organisations also come in all kinds of ownership structures, ranging from municipally owned wastewater treatment facilities to a family-owned industrial company to a multinational datacentre company that is listed on a stock exchange.

An important note: third-party producers can also exist in the form of 'prosumers': consumers that also supply heat, back into the system, in times they have surplus heat from their own production facilities or during times they have a cooling demand instead of a heating demand. These companies may consume heat during winter and supply heat during summer, or during certain times of the day. However, in contrast to the electricity market in many countries, the possibilities for prosumers in DH are currently limited. In Stockholm, Sweden there seems to be some potential for prosumers, as the city's DH company invites third-party producers with surplus heat to supply to the network (Stockholm Exergi, 2019). However, it is unclear how many cases there are of consumers that have both a heating surplus and a heating demand (which they cannot cover themselves).

Integrated DH company

Perhaps the most common form of a DH company is the integrated DH company. This can, however, still differ slightly within this stakeholder type. "Integrated", in this context, refers to the integration of two or more of the three main roles within the DH system – producer, DSO, provider – into one company. For example: a DH company can be called integrated if it fulfils the role of distribution system operator and of provider of heat to consumers. A DH company can also be more strongly integrated, if it also produces heat for its DH system. In theory, an integrated DH company can also be a producer and DSO, but not the provider of heat to consumer, although in reality this does not really happen. Probably the most common form of the integrated DH company is a party that produces, distributes and delivers heat to its consumers and thus integrates all three main roles. What is also very common is a DH company that integrates distribution and delivery, but feeds in heat from a third-party producer. When discussing an integrated DH company this will refer to one of these two main forms.

The activities of an integrated DH company range from developing new DH areas, operating and maintaining the DH grid and, if applicable, developing, operating and maintaining heat production facilities to installing heat delivery sets at consumers, customer services and billing to consumers. Companies sometimes outsource certain activities to subcontractors, for example outsourcing construction of a new DH pipe to a contractor.

Integrated DH companies can have many ownership structures, ranging from public ownership (e.g. municipalities) to private ownership (e.g. large energy company) to cooperative ownership (citizen cooperative), or combinations of these through public-private partnerships (PPS) or other joint ventures. Many DH systems in European countries are (partly) owned by the municipalities in which they operate. In some countries, like Denmark, cooperative ownership of integrated DH companies – both with/without production – is very common, even more than municipal ownership. Especially the smaller DH systems in towns in more rural areas are owned by cooperatives, where the larger DH systems in urban areas are municipally owned (Gorroño-Albizu, Sperling, & Djørup, 2019). In other countries private ownership of DH companies also occurs. However, in many cases this regards DH systems that were developed by a public organisation and which were later privatised. In some countries cooperative ownership is more common in sectors like electricity generation (e.g. cooperative wind turbine ownership) and is slowly transferring into the DH sector.

Transmission company

There are examples of companies that only fulfil the role of TSO in a DH network and thus form a separate stakeholder type. This is mainly the case in larger systems, as smaller systems often do not have a (large) transmission pipe, let alone an entire transmission grid. In some DH systems the role of TSO might be fulfilled by an integrated DH company or there is no transmission line in the first place, thus no TSO. In some – mostly large – systems the transmission company is mainly responsible for operating and maintaining a large transmission grid that is often connected to two or more distribution systems. The activities of the transmission company range from operating the transmission grid, connecting new distribution grids and production facilities, developing new transmission lines in order to do this and to balance the heat load on this grid.

In principle a transmission company only fulfils the role of the TSO; if it would also perform many other roles, it would not be considered a transmission company anymore. However, there are exceptions, as Denmark shows. The Greater Copenhagen (GC) DH system has not one, but even two transmission companies: CTR and VEKS. Although CTR only owns and operates a large transmission grid of 54 km and through that supplies 18 PJ annually to 5 distribution companies, VEKS also fulfils other roles. VEKS owns a 132 km transmission grid, through which it supplies 9 PJ to distribution companies in 12 different municipalities. However, it also owns and operates one of these distribution companies and is the owner of one of the CHP-plants in GC. Normally, this would be considered an integrated DH company, but as VEKS was founded as a transmission company and – by far – its main role is still that of TSO, it is considered a transmission company. Also, both the distribution company and the CHP-plant are placed within different subsidiaries.

Transmission companies – the few that exist – are generally publicly owned. They almost always cross municipal borders and therefore are larger than the local scale. Because of this regional scale and activity, ownership of transmission companies is normally shared between different municipalities in which it is active, or even lies with a national government. In the case of Greater Copenhagen, as discussed in chapter 5, both transmission companies of CTR and VEKS are owned by several municipalities – 5 and 12 respectively. In the less mature DH market of the Netherlands there currently are no transmission companies. However, the Dutch government recently appointed the national TSO for natural gas, Gasunie, as the developer and operator of a large new DH transmission pipe in the Rotterdam-The Hague metropolitan area.

Heat load planner

This stakeholder type is not very common and can generally only be present in very large DH systems where a transmission company is active. The definition of this stakeholder type is mainly based on the Greater Copenhagen case and is quite rare, but still considered a separate stakeholder type, given its remarkable and important role in the DH system. In the GC DH system two large transmission companies are active; CTR and VEKS. These have, together with the largest integrated DH company – HOFOR – established a company that is responsible for efficient planning of heat production for the transmission and distribution grids.

Such a company should function more or less independently, from transmission companies and integrated DH companies, but mostly from heat producers. It would be responsible for optimising DH load dispatch, based on a given set of criteria and targets. These targets may differ: should the heat load planner optimise towards the most sustainable energy mix in the DH system, towards the most reliable and stable production or should it aim for the lowest costs for heating? This depends on the targets that the heat load planner receives from its 'founders'; a heat load planner is normally not an organisation that takes the initiative to fulfil this role, but is established by other parties that have an interests in an independent party that is responsible for dispatch and heat planning. This is exactly the paradox of the heat load planner; it only exists by the grace of other, probably more powerful organisations, but is considered to act and operate independently in order to realise exactly the goals for which is was founded.

As said, the heat load planner, as a separate stakeholder type would normally be initiated by other stakeholders that have an interest in objective planning of heat dispatch, but based on subjective criteria and targets. The legal structure and ownership of the heat load planner thus depends on the character of its 'founding' partner(s). In the case of GC the heat load planner – Varmelast – was established in 2008 by the three municipally-owned companies of CTR, VEKS & HOFOR. In theory cooperative or private organisations could also establish a heat load planner, but especially with the latter the incentive for independent heat planning might be lower, as a private company usually wants to maintain a more direct form of control of its operations. Furthermore, establishing a heat load planner makes most sense in case of unbundling of different roles in the DH system, at least to a certain extent and especially between production and transmission/distribution. However, it is not often that absolute.

Independent distribution company

Although there are not many independent distribution companies yet, this number could be rising in the future. An independent distribution company is a stakeholder that only fulfils the role of DSO and does not act as a producer or provider of DH. The independent distribution company is the owner and operator of the DH grid and thus responsible for the activities of construction and, if necessary, expanding the DH grid to be able to connect production facilities and consumers, both residential and commercial/industrial.

As said there currently are very few DH systems with independent distribution companies. In the ones that do exist or are under development the independent distribution companies have varying ownership structures. In the Netherlands the call for independent grid operation has been rising over the last few years, resulting in a the development of a few new DH systems where the three main roles are unbundled. For example in the cities of Zaanstad, near Amsterdam, and Roermond, in the southeast of the country, there are DH systems under development in which third-party producer, an independent distribution company and an independent provider will be active. In each of these cases the independent distribution company is the non-regulated, commercial subsidiary of the Dutch holding companies for the regulated and non-commercial regional DSO's for electricity and natural gas. Although operating commercially, these companies are public ownership. There are also some citizen cooperatives that want to establish a DH system, although it is not always decided yet what the role of the cooperative will be. In principle, they can also operate as an independent distribution company, although it might be more logical for them to also carry out the delivery of heat to the consumer – which they are themselves.

Lastly, as mentioned there will also be independent DH providers in the developing systems of Zaanstad and Roermond. These could be considered as a separate stakeholder type; the *Independent provider*. In both cases this role is fulfilled by the same multinational energy company, that acts as independent provider for DH in these systems, but in principle this could be done by any kind of party, varying from a local cooperative that wants to be their own provider to a private company that operates independently from other stakeholders and their roles. Both the independent distribution company and the independent provider are far from common, but could be appearing more and more if independent grid operation and/or unbundling of roles in DH is desired.

6.2. Stakeholder interests and influence

Stakeholders in a DH system do not simply have roles to play, responsibilities to live up to and activities to carry out. They also have an interest in a DH system, as they want to receive some kind of value from their participation in that system – for example receiving a service, or receiving monetary value, or reaching organisational goals. They normally have a reason for being a stakeholder in the system, a reason for playing their role and carrying out their activities. These interests, which every stakeholder has to a lesser or greater extent, are important to study as they explain the actions and decisions of a stakeholder regarding that system, and the logic behind it. They also shape the DH system's design, as the interests of stakeholders shape their requirements towards that system. Collectively the requirements of all stakeholders, based on their individual interests, shape the system requirements or requirements specification.

To what extent different requirements are translated into the system requirements and ultimately the system's design is also depending on the degree of influence a stakeholder can exercise on the planning process. This influence also varies, probably at least as much as the stakeholders' interests vary. The influence a stakeholder has on the planning process does not necessarily reflect the interest it has in that system. For example: a DH system might be of great importance to an individual consumer, but that individual consumer might not be of equally great importance to the system. This potential imbalance could lead to problems, like decreasing societal support or misalignment between public goals and DH system functioning. Therefore it is also important to not only study a stakeholder's interests, but also the influence the stakeholder has on the system's design. This will be done in this section, according to the stakeholder descriptions of section 6.1.

The process of unravelling stakeholders' interests, distilling requirements towards the DH system from those interests, weighing different requirements into a set of system requirements and finally translating these requirements into a system design can be quite complicated. This section and the following chapters aim to provide support to the planning process by illustrating the relationships between different stakeholder interests, system requirements and the factors of a system's design that could be linked to those requirements. In order to do this, the following steps are taken:

1. Description of the interests of different stakeholder types and the influence each of these different stakeholder types generally has;
2. Coupling of these interests to possible requirements towards the DH system;
3. Linking of these requirements to the various factors that were described in section 3.2.

Figure 30 – Relationship between stakeholder interests, system requirements and factors in DH systems

These steps are illustrated in Figure 30.Note that these steps are not a guide for the planning process or a handbook for DH system design. These steps and the sections in which they are described are intended to raise understanding of the various stakeholders in a DH system, their interests and the influence they have or have not on the design of the system they are active in and/or rely on. This aims to provide insight on possible improvements for the planning process in different countries and the legal and organisational frameworks that support this process.

Municipality

As the most important public authority on the local level municipalities are vital for implementing national policy and realisation of public goals. However, they are organisations that also work on a relatively operational level and have to perform a wide range of tasks. This variety of responsibilities – both abstract, policy-oriented and concrete, operational – makes the municipality an intriguing stakeholder when it comes to their energy strategy. To execute this energy strategy and realise their targets regarding the energy transition, DH systems often are an important instrument to municipalities.

A municipality's energy strategy is usually built on three public goals: affordability, reliability and sustainability. These goals are often presented as a triangle with a corner for goal, within which a balance has to be found between the three (Tieben & Van Benthem, 2018, pp. 3-4). A municipality thus has to prioritise between these three goals, but can also formulate additional goals. Besides, these goals can change over time, especially because of political elections and changes in the societal support certain goals receive. When looking at the interests a municipality has in a DH system within its city boundaries, something that is often stated is that reliability is regarded as very important, but also considered to be rather obvious, a given fact, almost. Affordability of the city's energy provision is always an important objective to municipalities, as it has a responsibility to all its citizens, perhaps even the most to the less wealthy. However, what a municipality considers to be affordable might differ and the extent to which a municipality is willing to cover less profitable or even less financially feasible investments for the purpose of other goals is very much depending on the political colour of the city's sitting administration.

Lastly, sustainability is becoming increasingly important to municipalities, as it reflects the rising importance society attaches to it, which influences national and regional policy. Sustainability targets in these policies are translated into interests a municipality has in a DH system; when a municipality has a target to become carbon-neutral in 2025 or 2040, this means the heat provision through DH has to be fully sustainable before that year. The latter – a sustainable heat provision – is an interests of that municipality in the DH system. Whether this interest is met partially depends on the influence the municipality, and other stakeholders that share this interest, can exercise on the DH system.

In addition to these three well-known public interests – affordability, reliability and sustainability – municipalities can also have other, more specific interests as they could see different ways of realising their public goals. Some interests that are also mentioned are:

- Freedom of choice for consumers, both for a provider and a producer/source in the DH system;
- Transparency in both DH tariffs and in tendering for new DH developments;
- Participation of citizens in the DH system and/or its design.

A municipality can have all kinds of interests and preferences towards the DH system, but whether these are met depends on the influence it has. A municipality can influence a DH system in three ways; by facilitating, for example through permits and planning procedures, by stimulating, through subsidies and other funds, and by participating, through ownership and investments. The amount of influence a municipality can exercise on the design and operation of a DH system varies along with two things:

1. The degree to which a country's legislative framework provides the municipality with legal and economical tools to prohibit, demand, stimulate or discourage certain decisions and development in a DH system;
2. The extent to which a municipality has direct control over DH companies, mainly via (shared) ownership.

The municipality is also a party that could help other stakeholders getting more involved in the planning process and in doing so ensuring that parties that have a large interest in or even are strongly depending on a DH system can also exercise an equivalent degree of influence on the system.

National government

Like municipalities generally do, the national government also built its energy policy on the three public goals of affordability, reliability and sustainability. Being the highest public authority, the national government sets the boundaries for energy policies of lower governments. Both specific legislation on DH and more general climate and energy policy is of influence on the DH sector. The interests of a national government in a DH system are often not as direct as the interests of municipalities. National governments do – normally – not have an interest in one specific DH system, but primarily in the DH sector as a whole. Just like for municipalities, DH is also often an important tool for national governments in reaching their ambitions regarding the energy transition.

The national government, too, does not clearly favour one of the three public goals over the other. However, its attitude towards these three is quite ambivalent, as for example many national government in North-western Europe have ambitious energy transition policies, but still cannot directly prioritise towards the sustainability of DH systems, as their citizens' heat provision should be affordable and these citizens should also be able to rely on a very secure heat supply. This leads to the fact that for many national governments – and for many municipalities too – the three public goals are all considered important, but a reliable heat provision is frequently considered to be some sort of precondition and in practice affordability often seems to slightly be favoured over sustainability. In the Netherlands for example, DH tariffs are currently capped to a yearly maximum. This leads to the fact that investments in decreasing the CO_2e-output of the DH system always needs to be manageable within the boundaries that are set by this price cap (Swelsen, 2019). The opportunities there are to take steps to increasing sustainability in DH are often bounded by the leeway a government's focus on affordability leaves. Lastly, national governments have an interest in the potential of their DH sector to innovate (Van Dalen & Van Beuningen, 2019). They often aim to stimulate this, both directly, e.g. through subsidies, and indirectly, by creating the right market conditions, setting targets and enable competition.

The influence a national government has ranges from legislation, like the Danish Heat Supply Act or the Dutch Warmtewet, to economic and financial tools, like taxes on CO_2e-emissions or energy consumption and subsidies for DH development or sustainable production. The national government can participate themselves in DH systems, but this is done to a much lesser degree than it is done by municipalities. Legal and financial instruments are most important for a national government. Although these tools only have an indirect influence, they have a very significant impact on DH systems and on the DH sector as a whole.

Housing association

In contrast to both a municipality and a national government, a housing association does not have to represent the whole population, but only their tenants. This does not necessarily mean that they can prioritise much easier between affordability, reliability and sustainability of the DH system, although they could be more specific in determining their interests. The reliability of the heat supply through DH is considered a precondition, something that should be a given. It could be therefore be considered most important (Lund H. T., 2019). Housing associations generally are 'social' organisations for which the main objective is to realise affordable housing for low-income households (Schilling, Nikdel, & De Boer, 2018, pp. 37, 42). Because of this, the affordability of the heat supply is generally considered to be most important, both in terms of consumer-tariff and in terms of one-time connection fee (Lund H. T., 2019) (Van der Veek, 2019). The DH-tariff, both variable and fixed, is directly relevant for tenants. The connection fee is generally paid by the building owner, which in this case is the housing association, although it might be translated into the monthly rent or other service fees for tenants. Other relevant interests towards the DH system are for example having a comfortable and healthy indoor climate for their tenants.

Although housing associations are often legally organised as foundations or associations, they are not publicly owned. Still, they are important societal organisations and normally are strongly influenced by local and national governments.

Because of this, housing associations are expected to contribute to the sustainability goals of these governments, besides possible own ambitions the associations have in that area. Sometimes housing associations are also bound to political agreements they have co-signed (Schilling, Nikdel, & De Boer, 2018, p. 37). Naturally, this makes the sustainability of the heat provision through DH systems an important criteria for housing associations in considering to connect to these systems.

Because of their size housing associations are relatively influential within DH systems, especially compared to individual consumers and homeowners. This varies with the local conditions of the DH system, as in dense urban areas the share of dwellings owned by a housing association is generally larger than in smaller towns (Statistics Denmark, 2020) (CBS, 2020). Although the influence of a housing association is only indirect, as they normally do not financially participate through ownership of or direct investments in a DH system, the power they have over the decision whether or not to connect a great number of households, makes that they have a strong position in the viability of a DH system's business case. The tenants of the housing association also play an important role in this decision-making process, as there often is a minimum required percentage of tenants that needs to actively consent (Schilling, Nikdel, & De Boer, 2018, p. 37).

Individual consumer

Both the interests and influence of the individual consumer vary enormously. When this stakeholder type is divided into residential and non-residential consumers, it becomes slightly easier to describe these differences. Looking at residential consumer interests, these roughly depend on two things: the consumer's disposable (household) income and the consumer's personal preferences and values. Generally speaking a less wealthy consumer sometimes cannot afford to prioritise towards something other than affordability. A consumer with a higher income might be better able to put sustainability on first place and pay a higher price. However, this is still very much depending on personal preferences, as low-income households might still value sustainability highly. Individual consumers generally view the reliability of their heat supply as the most important, although trade-offs can be made towards other values, especially towards affordability. Besides the classic three goals, other interests might also play a role. Individual residential consumers might not only want a low energy bill, but also a comfortable indoor climate. Some might care a lot about having the freedom to choose; for a heat provider, perhaps also for a heat source or the sustainability of that source, or for connecting (or not) to DH in the first place.

Non-residential individual consumers are organisations that use buildings that range from offices to greenhouses and schools to factories, as long as the organisation has an individual contract with the DH company. Interests they have depend a lot on the consumer's organisational goals. One organisation might be focused on just having the lowest heating bill possible. For another consumer the reliability of the heat supply is of vital importance, for example when its production process depends on it. A third consumer could have organisational goals on sustainability and might be willing to pay a higher tariff for more sustainable heat sources. Some organisations might even be interested in the possibility to supply heat to the system, besides consuming; so-called (potential) prosumers. It is very difficult to generalise on the interests of non-residential consumers, as the variety of organisations is very large.

First, the influence an individual consumer has mainly depends on one thing: whether or not the consumer owns the building it uses. If it does not, the interests of that consumer are mainly promoted through the building owner, which may be a private person renting out a second home, or a real estate company that rents out stores in a shopping mall to 30 different shopkeepers. In these cases, both the tenant of the private person and the 30 shopkeepers may have interests and preferences regarding the DH system, but even though they have their own heating bill, their influence is very limited as they do not own the building and therefore, for example, do not control whether the building will be or remain connected to the DH system. This is illustrated in Figure 31.

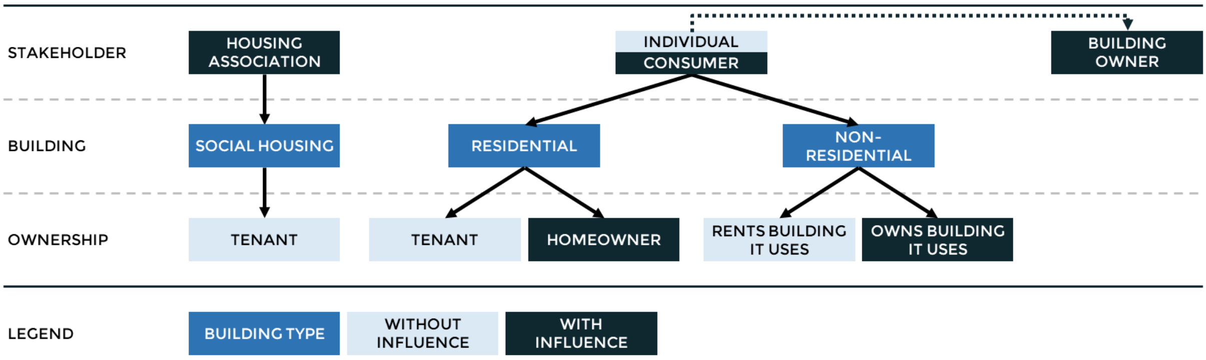


Figure 31 – The degree of influence the three stakeholder types that are involved in DH consumption and connection have depends on whether they rent or own the building they use (own illustration)

When the individual consumer owns the building it uses, two other things are important: the size of their connection and their yearly heat demand. Individual residential consumers normally have a very small connection – usually under 100 kW – and have an average annual heat consumption that is low; around 30 GJ (the Netherlands) or 60 PJ (Denmark), depending on the degree of insulation, the average floor area of a dwelling and the average heating degree days in the area (Segers, Van den Oever, Niessink, & Menkveld, 2019, p. 16) (Odgaard, 2019) (Danish Energy Agency, 2019, p. 35). Because of this small size an individual residential consumer does not have a strong influence and might not even be involved in the (later stages of the) planning process at all. The non-residential individual consumers might have a stronger influence, again, depending on their size. A large industrial facility that intends to be connected to a DH system might be able to negotiate about certain conditions, like on prices. This not only depends on the consumer's absolute size, but also on its relative size; its yearly consumption compared to the total heat supply through the DH system.

Building owner

The building owner as a stakeholder type is never the user of the building itself and thus not consuming any heat through DH itself. The interests of the building owner can therefore be quite different compared to the individual consumer, as users of the building. Additionally, building owners come in various forms and their interests may differ too. In general, building owners generally have the responsibility towards their users/tenants to guarantee the building can be properly heated. Consequently, the reliability of the heat supply might be considered most important, although reliability is often seen as obvious, a given. Furthermore, the building owner may not always be too interested in the DH tariffs, it often is interested in the (one-time) fee for connection to the DH system and possible additional costs for renovating or retrofitting the building to prepare it for DH (Rekenkamer Amsterdam, 2019, p. 55). Especially with profit-seeking building owners this might be considered very important. Lastly, depending on the personal preferences or organisational goals of the building owner, sustainability can be considered either not important or vital, and anything in between. For example when large institutional investors, like pension funds, own a (bunch of) buildings, they might value sustainability more than average, if their organisational goals tell them to invest their funds responsibly.

Besides the interests a building owner has, the extent to which it can exercise influence on the DH system varies significantly with the (total) size of the building(s) it connects to the system, just like it does for the individual consumer. This influence is also time-dependent: before and after signing a contract for DH connection. Before the building owner has its building(s) connected to the DH system it can exercise more influence, like in negotiating about the connection fee, about the tariffs that its tenants are going to pay (something that is also seen with housing associations) or even – if the owner is 'large' and thus influential enough – about more fundamental aspects like the level of sustainability of the DH system. Generally, though, the building owner has a limited influence, especially when not organised collectively.

Third-party producer

Because it only owns and operates one part of the DH system, the third-party producer might have a somewhat more narrow view on the DH system. Its interests in the system are often a reflection of this view and depending on both the organisational characteristics of the third-party producer and of the type of heat source it operates. Generally speaking the third-party producer wants a good price for the heat it supplies and, perhaps even more important, it wants to have some security it is able to sell the heat it produces (Lillethorup, 2019). If the third-party producer is a private, commercial company it usually has higher requirements regarding its expected return on invested capital than if the producer is a public organisation. However, both require security regarding sales of its supply, as the third-party producer needs a certain amount of heat sales to create a viable business case. Furthermore, the type of heat source is strongly related to the DH system's temperature regime. Connecting to a low temperature (LT) DH system might not be the most efficient for a high temperature (HT) heat source, and vice versa, as this could diminish the efficiency of both the production facility and the rest of the DH system. A temperature regime that fits the third-party producer's heat source is therefore a third interest.

The influence a third-party producer can exercise is always limited by the fact that it does not control the rest of the DH system. Still, the influence it has can be quite large, but depends on two aspects: the production capacity of the third-party producer's production asset(s) and the degree of competition from alternative production options. When the DH system is still to be developed, the third-party producer's capacity is large enough to supply the whole system and there are no serious alternatives, the third-party producer can have a significant influence. This is both before and after the DH system is put into service; before, the producer can negotiate about the supply contract and price, and after the DH company depends on the producer, both because there is a binding contract and because the producer supplies all the heat. However, when there are many alternatives or when a producer is not able to supply the whole system, it can have a weaker negotiating position. Lastly, when there already is a DH system in place and operational, an aspiring third-party producer, that is not connected to the system yet, has not much influence and is mainly depending on the DH company. The bargaining power is higher if there is regulation in place regarding third-party access (TPA) that requires the DH company to negotiate about access for the new producer. It might also help if the aspiring producer offers a better price or has lower CO_2e-emissions. However, whether the producer can gain access also depends on the existing assets of the DH company (when an integrated DH company) or the nature of the contract a DH company has with other third-party producers.

Integrated DH company

Probably the stakeholder with the highest interest and largest influence is the integrated DH company. This stakeholder type has a very large interest in a DH system because it controls most, if not all assets in that system. It also generally is the only DH provider that thus contracts all consumers in the system. The integrated DH company has different interests, ranging from a stable, balanced heat load within the system in order to meet the consumers' demand at any time, to a return on the invested capital, to – if the company also owns a production facility – the security of selling its heat production. The rate of return the integrated DH company considers appropriate may differ per company; a company owned by a municipality or by a citizen cooperative might accept a lower return than a private, commercial company. Furthermore, integrated DH companies frequently also have goals with respect to the sustainability of their DH system. These may be affected by the organisation's general purpose, or simply be ruled by policy and legislation (Nicolaï, 2019) (Honoré, 2019) (Van Soerland, 2019). In general, the interests of the DH company are mainly determined by the primary goals of the organisation that owns the DH company, whether this may be a municipality, a citizen cooperative or a private company. For example: a municipally owned integrated DH company might want to focus more on consumer experience and satisfaction (FORS A/S, 2019, p. 10).

As the integrated DH company fulfils most, if not all roles in the DH value chain and it is owner and operator of the distribution system – which is a natural monopoly and thus has no competition from other DH distribution systems in that area – it can be considered highly influential. Put simply, the integrated DH company can decide into which areas it will expand its DH system, what heat sources it will allow to connect, what temperature level the system will have, what investments it will make, what prices it will charge and how transparent it will be about its operations. However, only in theory the integrated DH company has this limitless influence. In practice many countries have laws and regulations that curtail this influence or steer the integrated DH company's influence in the right direction. Factors that can restrict the influence the company has on the issues mentioned are laws regarding transparency, obligatory connection, price regulation, urban and energy planning, third-party access and many more. Although the integrated DH company usually still has a much power, a country's legal framework determines the actual influence and responsibilities the company has.

Transmission company

In many DH systems, there is no transmission company. Only in very large systems and, normally, only when there is more than one municipality involved – and thus more than one distribution system – a transmission company can exist. When a transmission company does exist their main interest might be to guarantee a stable and balanced heat load in the transmission system and the connected distribution systems. The other two public goals – affordability and sustainability of the heat supply – generally are both important to the transmission company, but can often not be realised equally and therefore are traded off against each other (Holm, 2019). What choices the transmission company makes depends on its organisational priorities and the leeway that legislation leaves for prioritising towards one of the two. Transitioning towards a cleaner heat provision might be a top priority, but not at any price. Especially when a transmission company is publicly owned – which generally is the case – sustainability is often high on the agenda (Holm, 2019). However, transmission companies are often established because potential cost savings can be realised due to economies of scale and therefore also have a strong focus on affordability as a major organisational objective. This shows very much the delicate balancing act the transmission company has to perform.

The influence a transmission company can exercise on a DH system is significant, as it controls a vital part of the DH value chain. Still, the transmission company 'only' fulfils one role – that of TSO – and is therefore not actively involved in activities like heat production or delivery to consumers. Also, a transmission company might only be established when there already are several distribution systems and there is a somewhat mature DH sector in an area. Then, it might be harder to fully influence the DH systems' designs and operations. Nevertheless, the transmission company has a cross-border influence between municipalities. It can also be considered an important party in achieving municipal goals towards sustainability (Holm, 2019). It will also be influential towards (integrated) DH (distribution) companies, as they will depend on the transmission company for their heat supply. Towards (third-party) heat producers, the transmission company is probably the most important stakeholder, as they do not have direct relations with DH companies nor with consumers.

Heat load planner

As discussed in section 6.1 this stakeholder type is quite rare and only present in very large DH systems with a transmission company. The heat load planner is responsible for efficient planning of heat production and operates independently. As the heat load planner is normally established by other stakeholders in the DH system, the criteria it uses are given by those 'founders'. Therefore, the interests a heat load planner has very much depend on the assignment it receives from its founders. In the Greater Copenhagen case the heat load planner (Varmelast) was established by two transmission companies and the largest of the integrated DH companies and given the task to economically optimise the heat production in the GC DH system, towards the lowest heat production costs, but given a certain boundary condition in terms of security of supply. Consequently, it is in the interest of the heat load planner to achieve a highly reliable and affordable heat provision. The sustainability of the DH system is not of any concern to the heat load planner in GC, simply because it is not its duty to pursue this. However, if the founders/clients of the heat load planner decide to change the scope or purpose of the heat load planner's responsibilities, this might change.

As a result of the relationship between the heat load planner and other stakeholders, it can be easily concluded that the heat load planner does not have a large, direct control over the DH system design. However, given its large responsibilities, great expertise and pivotal role in the centre of the system, the influence of the heat load planner can still be considered substantial. It might not have a very direct influence and does not set its own targets, but is does have to work closely together with its founders – which generally are transmission and/or distribution companies that have a larger influence – and has scarce and valuable knowledge and experience.

Independent distribution company

Being a stakeholder that only fulfils the role of DSO in the DH system, the independent distribution company does not have any responsibilities towards heat production or delivery to consumers. This does not mean that it is not of interest to the independent distribution company. Safely and timely distribution of heat is one of the responsibilities of the distribution company, which makes maintaining a stable heat load at all time one of its interests. Besides this, the investments in distribution grids are quite high and often cover the majority of total investments in a DH system. Therefore it is also in the interest of the independent distribution company that it can recoup these investments, which makes a low load/connection risk another main interest. Furthermore, the company generally also wants to make a certain return on the invested capital in the distribution grid. What yield requirements an independent distribution company applies mainly depends on whether it is a private, public or cooperative company. The last two usually have a lower return requirement than private companies. However, this does not necessarily mean consumer tariffs are lower too, as that also depends on a multitude of other factors.

Because an independent distribution company only fulfils one role in the DH value chain it does not have control over the whole system, but needs to closely cooperate with other stakeholders like (third-party) producers and an independent heat provider. Still, the independent distribution company will normally have a monopoly on distribution and thus is always included in the total DH system. The influence an independent distribution company has is therefore large, although a little lower than the integrated DH company. As it does for the integrated DH company, a country's legal framework also determines the actual degree of influence and responsibilities the independent distribution company has.

6.3. Conclusion

When looking at different DH systems in two countries, interviewing a wide range of stakeholders and experts and reviewing a load of reports and other documentation, ten different stakeholder types can be distinguished. In this chapter, an answer to the first part of the second sub-question is formulated.

SQ2	What are the characteristics, interests and influence of the main stakeholders in a district heating system in a metropolitan area and what are the resulting requirements towards the system?

These ten main stakeholders fulfil different combinations of roles and have varying responsibilities and tasks. They also have very different interests towards the DH system they are active in, although there is also some common ground. The level of influence each of these stakeholders can exercise possibly varies even more, depending on the local characteristics and legal framework. Influence and interests do not always correspond: some stakeholders, especially individual consumers, have a very high interest in the DH system, but have little influence on the planning process and the system's operations. How these stakeholders compare to each other in terms of interest and influence, is illustrated in a power-interest grid in in Figure 32.

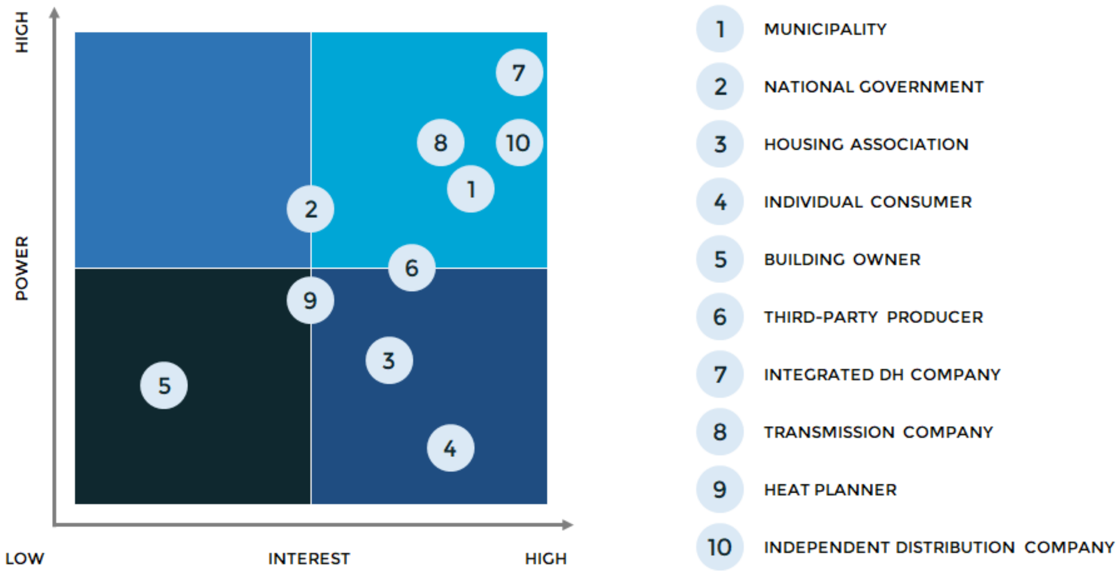


Figure 32 – The ten main stakeholder types in metropolitan DH systems are plotted on this power-interest grid, showing the degree of interest and amount of influence a stakeholder type has on average (own illustration)

It can be seen that the stakeholder types that own and operate a (part of the) transmission or distribution system generally have the greatest influence in the DH system's design and operation. This does also reflect their large interests, mainly because of the fact they have invested large amounts of money in their grids and other assets. Furthermore, the two main types of government are also quite influential, with the difference that a municipality has a significantly higher interest in a specific DH system, which lies within its municipal boundaries, and the national government has a lower interest in a specific system, but a very high interest in the DH sector as a whole. The third-party producer has a slightly lower influence, as it is depending on the operator of the transmission or distribution grid to be able to sell its heat. The heat load planner has a certain degree of influence, but this is mostly because it receives a mandate from other influential stakeholders. The three stakeholder types that 'only' connect to and/or consume from the DH system are the least influential, although they are often quite dependent on the system, especially when there is an obligation to connect or there simply is no (suitable) alternative heating technology for their building.

The content of stakeholders' interests varies even more than the degree of interest (and influence) does. The 14 main interests are shown in Figure 33. Some are shared by a wide range of stakeholders, like a secure supply to consumers, some are more specific for one or few stakeholder types, like the objective for strong innovation in the whole DH sector.

LEGEND

STAKEHOLDER INTEREST
interest to stakeholder
no interest to stakeholder

Municipality → **mun**
National government → **gov**
Housing association → **has**
Individual consumer → **ico**
Building owner → **bow**
Third-party producer → **tpp**
Integrated DH company → **idh**
Transmission company → **trc**
Heat planner → **hpl**
Indep. distribution comp. → **idi**

STAKEHOLDER INTEREST	1	2	3	4	5	6	7	8	9	10
SECURITY OF SUPPLY TO CONSUMER	mun	gov	has	ico			idh	trc	hpl	idi
LOW CONNECTION FEE			has	ico	bow					
LOW HEATING COSTS			has	ico						
FREEDOM OF CHOICE	mun			ico						
"OPENNESS" OF DH SYSTEM	mun					tpp				
SUSTAINABLE HEAT PROVISION	mun	gov	has	ico						
INNOVATION IN DH SECTOR		gov								
COMFORTABLE INDOOR CLIMATE			has	ico						
SECURITY OF SELLING HEAT PRODUCTION						tpp	idh			
LOW CONNECTION RISK							idh	trc		idi
RETURN ON INVESTED CAPITAL						tpp	idh	trc		idi
STABLE HEAT LOAD							idh	trc	hpl	idi
COST-EFFICIENT OPERATION						tpp	idh	trc	hpl	idi
SOCIETAL SUPPORT FOR DH	mun	gov								

Figure 33 – The fourteen main interests of the ten stakeholder types in DH systems in metropolitan areas (own illustration)

When again looking at the power-interest grid in Figure 32, it needs to be noted that when one should draw the diagonal from the lower left corner to the higher right corner of the grid, this diagonal roughly represents a balance between the level of interest and the degree of influence the stakeholder has. Stakeholder types that strongly deviate from this diagonal are considered to have a disbalance between their interest and their influence. Naturally, there may always be some degree of deviation, but the disbalance between interest and influence that can be seen with individual consumers is remarkable. When reflecting on and evaluating the heat planning process, this should be a focal point and could leave room for improvement. More on this in chapters 8 and 10.

7

REQUIREMENTS ANALYSIS

Stakeholder interests, system requirements and their relations

Ørsted's *Avedøreværket* CHP-plant, Hvidovre

Where interests only tell something about what a stakeholder wants, needs or demands from a DH system, they do not specify what this means for the design, organisation and regulation of the DH system. This is the main difference between stakeholder interests and system requirements. Although stakeholder interests or needs can be quite specific, they generally do not prescribe what is required to meet those needs. System requirements do in fact specify what is required on different aspects of the system's design and organisation, varying from technical or physical requirements, to requirements regarding regulation of the DH system and many things in between. Connecting stakeholder interests to possible system requirements can provide insights on what a system needs to achieve in order to comply with those interests and what design decisions can be made to realise this.

This chapter will answer the second part of the second sub-question.

SQ2	What are the characteristics, interests and influence of the main stakeholders in a district heating system in a metropolitan area **and what are the resulting requirements towards the system?**

The first section of this chapter aims to identify the requirements that are mentioned or suggested by stakeholders and experts. What do stakeholders themselves think about possible ways to meet their interests, what do they suggest could help the system in answering their demands? And what do independent experts think about possible ways to properly respond to stakeholder interests?

In the second section the identified requirements will be linked to interests of different stakeholders. What do stakeholders and experts think about the relationships between interests – both their own and of others – and system requirements? An iteration is made to not only identify which system requirements are mentioned by a single stakeholder to meet its interests, but to also look at what other interests – perhaps of other stakeholders – can be linked to a certain requirement. This could assist in finding common ground between stakeholders and their different interests and in identifying possible trade-offs between interests.

7.1. Identification of requirements

During the stakeholder interviews that are conducted in both the Greater Copenhagen and the Greater Amsterdam area, many stakeholders discussed not only their interests, but also the system requirements they believed would help meeting their interests. Furthermore, in interviews with independent experts these and other requirements were suggested that could benefit one or multiple stakeholder interests. The system requirements mentioned by stakeholders and experts vary from physical system requirements, like having a low-temperature system, to requirements regarding market conditions or aspects of the regulatory framework, like having multiple producers in a DH system or voluntary connection for consumers.

In this section these requirements are identified and briefly described. Requirements that are mentioned by stakeholders or experts are supplemented by a brief description of what is demanded from the system by this requirement and what the intended general effect would be (see Table 8). The identified requirements are divided in the same four categories as the factors in section 3.2. The list of identified system requirements is certainly not suggested to be exhaustive; there may be and probably are many more system requirements that could be relevant. However, this list simply represents the main system requirements mentioned in stakeholder and expert interviews that were conducted in Greater Copenhagen and Greater Amsterdam.

SYSTEM REQUIREMENT	DESCRIPTION
TECHNICAL AND PHYSICAL REQUIREMENTS	
Little heat lossed in transmission and distribution	The heat losses in the transmission system and distribution system should be low to increase fuel and energy efficiency.
Low temperature DH system	The temperature in the distribution system should be below a certain level. This could lead to lower losses or easier connection of low-temperature (renewable) sources.
Mandate low CO_2e-emission sources	Connected and utilised heat sources should have a low CO_2e-emission level. This regards both the production technology and the fuels/sources that are used.
Forward temperature high enough	The forward temperature of the water in the system should be high enough, to ensure buildings with a lower level of insulation and/or inferior heat delivery system are also able to reach a sufficient indoor temperature.
Return temperature low enough	The return temperature of the water that leaves the buildings should be low enough, so that a sufficient amount of energy is extracted from the water to ensure high efficiency in the DH system.
Include storage capacity	A certain volume of storage capacity should be included in the DH system to be able to balance the network, store temporary production peaks and supplement production during consumption peaks.
Integration of DH system with power network	The DH and power systems should be integrated to be able to absorb ups and dows in energy production and consumption in both systems.
High connection density per km²	The DH system should have a high number of connections per km², in order to bring the average infrastructure costs per connection down.
REGULATORY AND POLICY REQUIREMENTS	
Transparency in tendering process	The tendering process, that is generally initiated by a municipality, should be fully transparent in terms of assessment criteria, evaluating procedure and the awarding to the successful bid.
Consumers connect voluntarily	Consumers should be free to connect when there is a DH system in their area and thus be able to choose whether or not the want to be connected or arrange a heating technology for themselves.
Early and final connection decision	Early in the DH design process it should be clear and final what percentage of consumers will connect to the DH system in their area.
Set binding sustainability targets	Binding targets to enhance sustainability and energy efficiency in DH systems should be imposed and enforced, in order to oblige companies to find a way to meet those targets and increase sustainability.
Long-term permit for integrated DH company	When an integrated DH company is awarded in a tendering process, it should receive a permit for a very long term. This would for example bring financing costs down and ensure sufficient time to recuperate investments.
ECONOMIC REQUIREMENTS	
Multiple producers in system	There should be multiple heat producers in the DH system – none should cover 100% of total heat production – in order to reduce dependency on one party, increase competition and having options to choose from.
Multiple providers in system	There should be multiple heat providers in the DH system to ensure consumers have options to choose from and providers can diversify in their propositions, e.g. based on different sources or prices.
Cost-based tariff	The DH tariff and its components should be purely cost-based, making sure prices are only as high as strictly necessary.
Cost-based tariff + profit	The DH tariff and its components should be based on actual costs and allow an additional profit margin to attract investments from private parties.
Contractual obligation to produce	There should be the possibility for DH companies and (third-party) producers to agree on a contractual obligation to have a certain production capacity available and, if required, produce a max. volume of heat.
No heat purchasing agreements	There should be no fixed heat purchasing contracts that guarantee producers a minimum heat sale to the DH company.
Taxes on non-sustainable heat production	Non-sustainable heat production should be taxed more than sustainable production, for example through a CO2-tax on heat production or via additional taxes on fossil fuels.
Benchmarking of DH systems	DH systems should be benchmarked against other, similar DH systems, in order to create competitive pressure and increase transparency.
Integration of roles in DH system	The main roles in a DH system should be integrated into one company, in order to control the whole value chain and be able to optimise production, distribution and delivery.
SOCIETAL REQUIREMENTS	
Include consumers in DH system design and operation	Consumers should be included in the design process of the DH system and the operation of their heating supply, for example in optimising heat consumption to better follow peaks in renewable heat production.
Transparency of DH tariffs	It should be transparent on what consumer tariffs are based, what the actual costs are and what the division of DH tariffs over different cost components is.

Table 8 – The main system requirements that were discussed by stakeholders and experts in GC and GA

As can be seen in Table 8, the majority of identified requirements are in the technical and economic category. The factors these requirements are related to differ significantly, although many requirements regard the system's temperature regime, main heat source and DH tariff. It needs to be noted that these requirements are not specified.

Normally, system requirements need to be carefully and specifically described in order to be useful in a system's design. For example: a requirement would not be to have a high connection density, but to have a connection density of >500/km², or something similar. As there is no system that is actually being designed in this research, yet the relations between stakeholder interests and system requirements are studied, these requirements describe the subject and direction of a requirement, but do not specify the exact details, as these are highly dependent on the context of the DH system that is being designed.

7.2. Relation between interests and requirements

The system requirements that are discussed or suggested by stakeholders and experts are briefly described in the previous section. This section will go into the relations between the 14 stakeholder interests that were identified in chapter 6 and the 24 system requirements that are described in section 7.1. These relationships can be described in two ways, in opposite directions:

1. *From stakeholders, via their interests to system requirements, so following the heat planning process*; each stakeholder interest is relevant to one or more stakeholder types. Each stakeholder interest is also related to a number of system requirements that could contribute to meeting that interest, or could in fact limit meeting that interest.
2. *From system requirements, via stakeholder interests to affected stakeholders, so in opposite direction*; when these relationships are turned around, another picture is painted. When looking at a certain system requirement, that requirement can relate to a range of stakeholder interests and either positively or negatively affect that interest. Each of these interests is, in turn, shared by a number of stakeholders.

Both of these ways to describe the relationship between interests and requirements are relevant. Stakeholder interests can be affected by several system requirements, as illustrated in Figure 34. In this example the stakeholder interest of *security of supply to consumer* – which is an interest that is shared by eight out of the ten identified stakeholder types – could benefit from four system requirements, as described in Table 8: *Integration of DH system with power network*, to have *multiple producers in system*, to *include storage capacity* and to have a *contractual obligation to produce*.

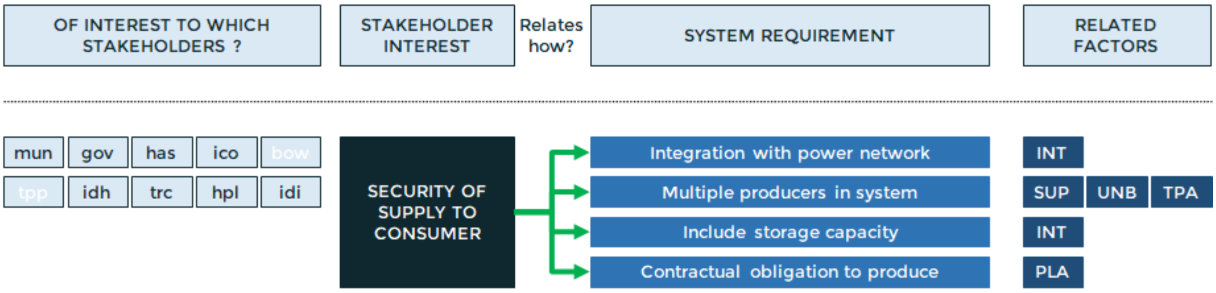


Figure 34 – The relationship between the interest of having a secure heat supply and several system requirements

The eight stakeholder types on the left of Figure 34 could argue for these four system requirements to be incorporated into the schedule of requirements in order to promote their (shared) interest of having a secure heat supply. This figure also shows the factors, as discussed in section 3.2, that are related to these four system requirements. Incorporating

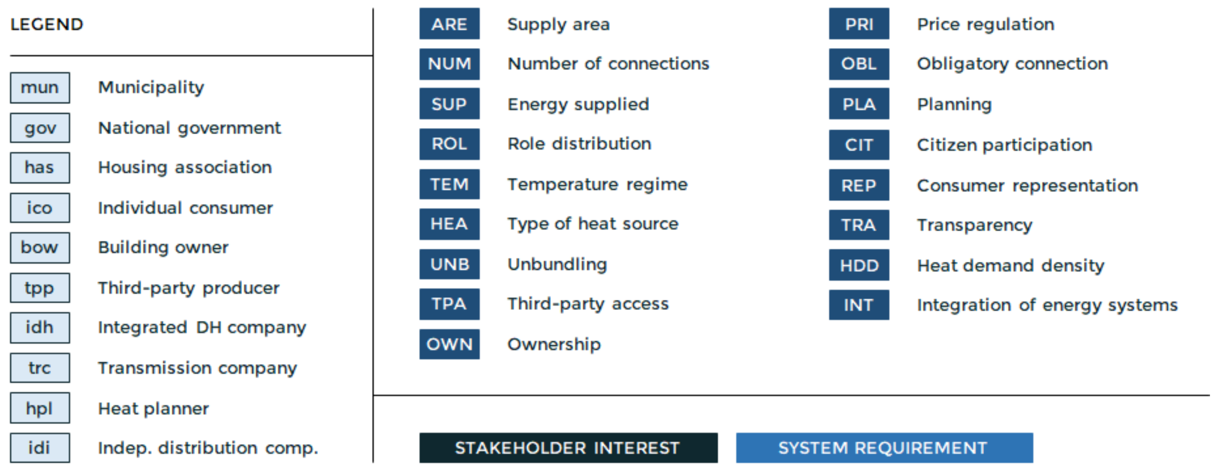


Figure 35 – The legend for Figure 34 and Figure 36, showing the ten stakeholder types and different factors of DH systems.

these requirements in the DH system has consequences for the factors that are mentioned on the right. More on the relation with (system design) factors in chapter 9. Figure 35 shows the legend for factors and stakeholders.

This first way of describing the relationship between interests and requirements illustrates what requirements affect a certain interest. The second way to describe the *interest-requirement relationship* shows which stakeholder interests can be influenced by a single requirement and how this affects different stakeholders. Figure 36 provides an example of this; the requirement of having *multiple producers in system* not only has an influence on the interest of having a secure heat supply to consumers, like shown in Figure 34, but also affects other interests and therefore other stakeholder types. This way of representing the relationship between interests and requirements provides additional information, for example on how a single requirement can affect a certain stakeholder type in multiple ways – like the individual consumer in Figure 36 – and on how trade-offs could be made between different interests and the associated requirements.

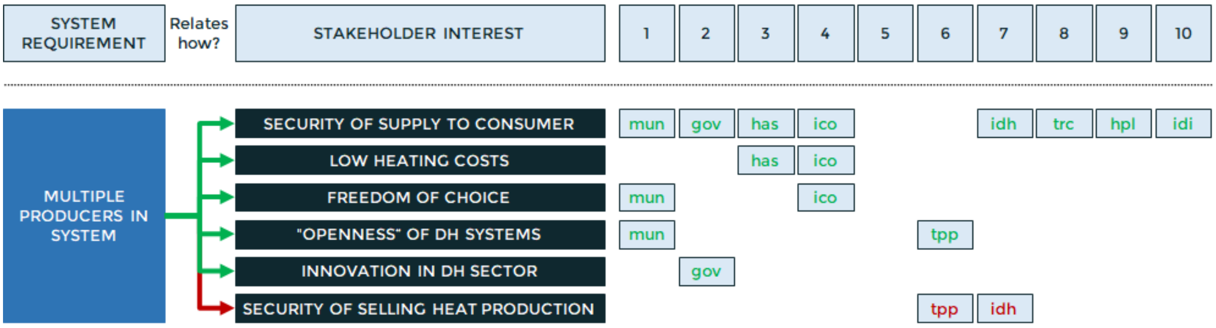


Figure 36 – The relationship between the requirement of having multiple heat producers and several stakeholder interests

Both ways to describe these relationships are illustrated for all 14 stakeholder interests (as identified in sections 6.2 and 6.3) and 24 system requirements (as identified in section 7.1) in Appendices F and G respectively. The relationships in Appendix F show what stakeholders share an interest and which requirements could support meeting that interest, like in Figure 34. The relationships in Appendix F provide insight on the effect a system requirement might have on different stakeholder interests and which stakeholders are affected by that requirement, like in Figure 36. However, the figures do for example not claim that certain possible effects of requirements on interests are always going to be present, or that all stakeholders that share a certain interest are equally affected by a certain system requirement. Furthermore, whether a stakeholder is affected and if so, either positively or negatively, also depends on other elements. For example (see Figure 37): whether the *return on invested capital* (interest) of an *integrated DH company* (stakeholder type) is negatively affected by a *cost-based tariff* (requirement) depends on the yield targets the company has, which might be influenced by the character of its owners – are these public or private parties? Also; what is included in a cost-based tariff, to what extent does it leave room for a (modest) return? Still, cost-based tariff regulation can be considered to have a predominantly negative influence on the return on invested capital of an integrated DH company (and other stakeholders that share this interest), especially compared to a *cost-based tariff + profit*.

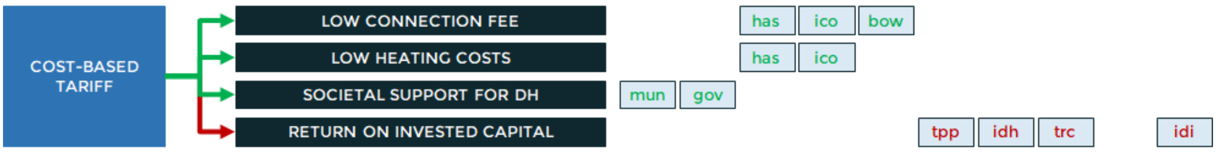


Figure 37 – The relationship between the requirement of having a cost-based DH tariff and several stakeholder interests

What do the these relationships – both illustrated in "way 1" and in "way 2" – demonstrate and what not?

- For each of the 14 interests, as illustrated in Appendix F, it is shown which requirements could be put forward by the affected stakeholders to promote their (shared) interest. This does not imply that the connected requirements *should* be included or that they would be desirable for all stakeholder types in any given case. Whether a requirement is in fact desired depends on several other factors. For example when looking at Figure 35; if an integrated DH company in fact wants to have multiple producers in its system depends on that stakeholder's other interests and the context of the DH system itself. Other producers could create competition for the integrated DH company and might not be desirable for that specific stakeholder. However, in general this requirement of having multiple producers is considered to have a positive effect on security of supply;

- For each of the 24 requirements the expected effect on different stakeholder interests is presented in Appendix F, showing an either predominantly positive or predominantly negative effect. Whether a certain interest is indeed affected in a real case and if yes, if this is a negative or positive effect, always depends on the specifics of the case. For example: not having a heat purchasing agreement might have no effect on the return on invested capital of a producer, if it is the only producer within the DH system;
- System requirements are analysed as independent, isolated requirements. In practice, requirements cannot easily be isolated but need to be considered in connection to other requirements to evaluate the expected effects on stakeholders. However, this would make analysis of the influence of requirements on interests very hard, especially outside of the specific case context;
- The characteristics of a certain stakeholder – within the stakeholder type – also have an influence on the relationship between requirements and interests. Whether a requirement has a positive, neutral or negative effect on a stakeholder interests might also depend on characteristics like personal preferences (e.g. for consumers), ownership type (e.g. for independent distribution companies) or organisational goals (e.g. for building owners or heat load planners);
- The relation between requirement and interest does not say anything about the 'strength' of that relationship: there might be a stronger relationship between the interest of having *low heating costs* and the requirement of *benchmarking DH systems* than between the interest of having a *cost-efficient operation* and the requirement of having a *return temperature* (that is) *low enough*. Furthermore, to what extent a stakeholder type has a certain interest might differ between types, within the same interest. The magnitude of the effect – either positive or negative – of a certain system requirement on a stakeholder can thus vary.
- Lastly: this section shows a way to analyse and illustrate the relationships between system requirements and stakeholder interests. It is not at all a guideline for drafting a set of system requirements or a DH system design handbook;

Given the limitations of the analysis of system requirements and stakeholder interests, what can be deduced from this analysis, as fully illustrated in Appendices F and G? What is quickly noticed is that all stakeholder interests relate to more than one requirement. In fact, 11 out of 14 interests relate to four or more requirements, either positively or negatively. This indicates that there are several ways to promote a stakeholder's interest. Furthermore, it is clear that the majority of interests has more positive than negative relationships with requirements. Only the interests of having *freedom of choice* (for consumers), having *security of selling heat production* and having a (desired) *return on invested capital* show many negative links to requirements. Especially the *return on invested capital* is negatively affected by a wide range of system requirements, as can be seen in Figure 38. This seems to be caused mainly by requirements that aim for improved affordability for consumers or increased sustainability of the heat supply. When looking at the situation in the Greater Copenhagen DH system, it is noticed that requirements like *benchmarking DH systems*, having a *cost-based DH tariff* and demanding *transparency of DH tariffs* are all incorporated in the DH sector and are not considered a threat to the interest of having a (sufficient) return on invested capital, as all DH companies are municipal or cooperative organisations and therefore not profit-seeking.

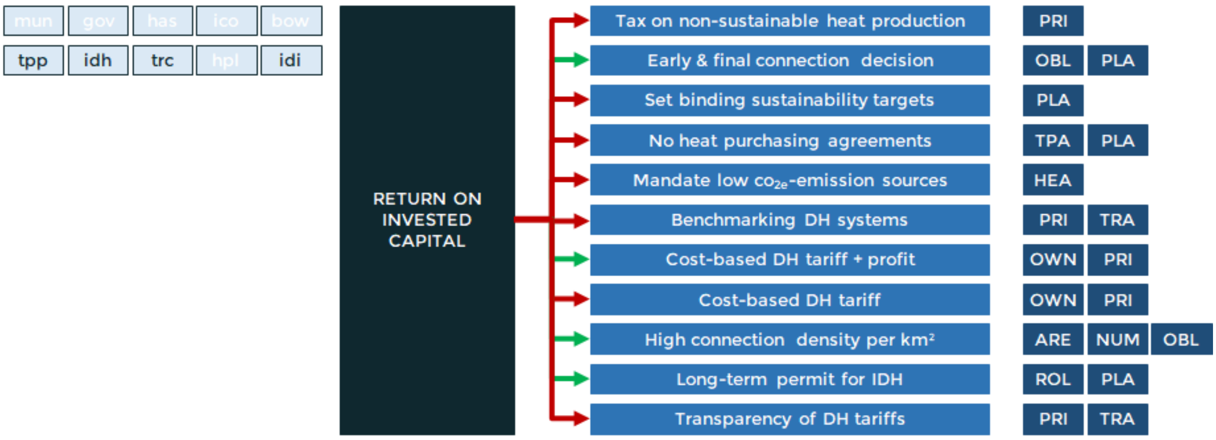


Figure 38 – The relationship between the interest of making a return on invested capital and several system requirements

Like each of the interests relates to multiple requirements, all requirements – logically – have an effect on more than one interest, in most cases even on more than three. Hence, a certain requirement can support one stakeholder type through several interests at the same time, as can for example be seen in Figure 36: having multiple producers in the DH system can be beneficial to the *individual consumer* through three of its interests. Also noticeable is the fact that most system requirements have more positive than negative links to interests. This does make sense, as these requirements are suggested in order to have a positive influence. These two facts provide the possibility to look for trade-offs within the planning process. When a certain system requirement is expected to have a positive influence on multiple interests and a wide range of stakeholders, but negatively affects a few stakeholders trough one shared interest, looking for trade-offs might assist in drafting a conceptual system design that is a well-balanced compromise between all stakeholders.

For example (see Figure 39): when *voluntary connection for consumers* is considered to have a positive effect on the *freedom of choice for consumers* and *societal support for DH* – relevant for the *municipality*, *national government* and *consumers* – but negatively affects the *integrated DH company*, *transmission company* and/or *independent distribution company* (whichever applies) through a *higher connection risk* (Dutch: vollooprisico), looking for a trade-off might help.

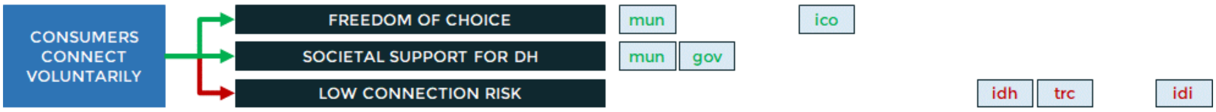


Figure 39 – The relationship between the requirement of voluntary connection to DH and several stakeholder interests

As including consumers in the design and/or operation of DH systems (see Figure 40) might decrease the connection risk (and boost societal support on the side), this might be a solution that could compensate the absence of an obligatory connection to DH for consumers. Whether or not this is applicable in a certain case where a DH system is designed; this is a way the analysis of Appendix F can assist by increasing the understanding of these relationships.

Figure 40 – The relationship between the requirement of including consumers in design and several stakeholder interests

Another insight that needs to be addressed is the fact that many interests are either relevant to (a selection of) the stakeholder types with numbers 1 to 5, or to (a selection of) stakeholder types with numbers 6 to 10, as can be seen in Figure 36. These numbers are not random; the first five stakeholder types have a somewhat 'passive' role in the DH system, as they do not perform any activities besides – put simply – being connected to or facilitating/regulating DH systems; the numbers 6 to 10 have an active role in the DH system as producer, TSO, DSO or provider, or a combination of these. When looking at the adjusted *power-interest grid* in Figure 41, it becomes quite clear that the second group of 'active' stakeholder types has, on average, a larger influence on the system's design and operation than the 'passive' group has. However, as was already concluded in section 6.3, this does not necessarily correspond to a stakeholder's interest. Moreover; these five 'active' stakeholder types are (almost) never all present in a DH system at the same time.

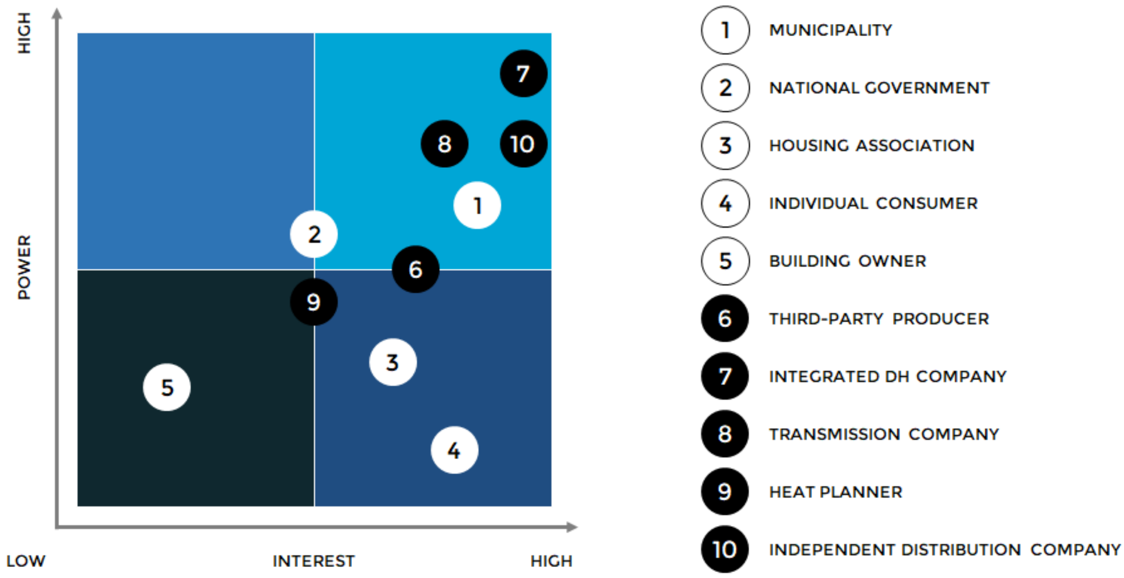


Figure 41 – Power-interest grid, adjusted from Figure 32, showing the 'active' (in black) and 'passive' (in white) stakeholder types and the degree of interest and amount of influence they have on average (own illustration)

In many cases, only one (e.g. *integrated DH company*) or two (e.g. *third-party producer & independent distribution company*) stakeholder types are present. The 'passive' five are almost always all present. This shows an even greater disbalance between interests and influence; not only looking at interests and influence of a stakeholder type, but also groups of stakeholders. This should not be taken lightly when analysing the planning process in chapter 8.

Again, many interests are relevant to either the 'active' stakeholder types, or to the 'passive' stakeholder types. This leads to the fact that for many requirements either the active or the passive group of stakeholder types is affected. In fact, in many cases the active group is positively affected and the passive group is negatively affected, or vice versa. This polarization of stakeholder interests can become a problem, especially when one of the two groups of stakeholder types is more powerful than the other. There are three possible directions for finding a solution:

1. **Alignment of interests;** more stakeholder types should share the same interest and thus all benefit or all suffer from a certain system requirement. This is not easy, but could in some cases be reached. An example in Figure 42; municipal or cooperative ownership – like is the standard in Greater Copenhagen – of the (integrated) DH company would align the interests of a *low connection fee*, *low heating costs* and *societal support for DH* to the 'active' stakeholder types that are present, as they are owned by the stakeholder types that benefit. Also, a lower return on invested capital would be less of a problem for the municipality or consumers, as public organisations generally have lower yield targets.

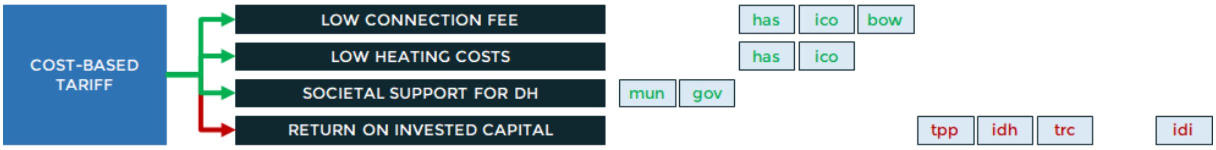


Figure 42 – The requirement of having a cost-based tariff, showing opportunities for alignment of interests (own illustration)

2. **Compromise system requirements;** system requirements need to be carefully specified for each particular planning process. By adjusting the exact specifications of a certain requirement to be an acceptable compromise between all parties, certain requirements might be easier incorporated in the system design.
3. **Trade-offs between requirements;** matching system requirements to compensate negative effects of one requirement on a certain interest with another requirement that has a positive effect on that interest. An example is given in Figure 39 and Figure 40, regarding voluntary connection to DH for consumers.

7.3. Conclusion

There are very large numbers of system requirements that can be considered and specified. Although every DH system in a metropolitan area has its own set of requirements, there are some widely shared requirements that can be identified. In this chapter, an answer to the first part of the second sub-question is formulated.

SQ2 What are the characteristics, interests and influence of the main stakeholders in a district heating system in a metropolitan area **and what are the resulting requirements towards the system?**

The first section briefly describes the most important requirements that are discussed by the ten main stakeholder types – and a few independent experts – in the DH systems of the metropolitan areas of Greater Copenhagen and Greater Amsterdam. This ranges from requirements regarding DH market conditions, rules and regulations, technical aspects and societal demands.

The second section dives deeper into the relationships that can be distinguished between these system requirements and the main interests of these ten stakeholder types. All requirements affect multiple interests and the majority of requirements has more positive than negative links to interests. This indicates there is a possibility to explore potential trade-offs between requirements, where combinations of requirements could achieve an acceptable outcome for all stakeholders. However, not all stakeholders have an equal influence on the DH system design and operation. When comparing the five 'active' stakeholder types – which fulfil a role in the DH value chain – with the five 'passive' stakeholder types, it is clear that the latter have a smaller influence. Combined with the fact that many requirements either positively influence the 'active' or the 'passive' stakeholder types, this leads to an imbalance that could be problematic when a DH system design that satisfies all stakeholders is pursued. There are three ways to approach this imbalance: by seeking alignment of interests, searching for a compromise within system requirements and by making trade-offs between different requirements. The next chapter will analyse the planning process and look for other challenges in practice.

8

PLANNING PROCESS ANALYSIS

Heat planning in Denmark and the Netherlands

By & Havn's *Svanemølleværket*, former CHP-plant, future Danish Museum of Science & Technology, Copenhagen

To be able to illustrate how DH systems can support stakeholders in their transition towards a sustainable heat provision, it is important to fully understand how these systems are designed. Furthermore, investigating whether all stakeholders are directly involved or indirectly represented provides insight on possible improvements of the planning process and the framework that support this. Also, knowing what challenges are faced in this process could increase the chances of a DH system in properly supporting all stakeholders in the energy transition.

This chapter will answer the third sub-question.

SQ3	How are district heating systems currently planned by stakeholders in metropolitan areas and what are the main challenges?

First, the general planning process of DH systems in Denmark and the Netherlands is discussed. This will go into the general framework for this process; from high-level objectives and policies of the national government, to more specific and operational procedures of regional and local governments. Based on this, specific elements of the planning processes of the Greater Copenhagen and Greater Amsterdam DH systems are discussed too.

Secondly, the way the planning process includes and prioritises the various stakeholder interests is analysed. Whether every stakeholder is represented appropriately and how different interests are weighed against each other is determined, again for both Greater Copenhagen and Greater Amsterdam.

Lastly, it is studied to what extent the planning process and the eventual design leave room for adaptability of the DH system. As many European countries have yet to get the energy transition going and technologies are – and are expected to stay – developing in the near future. Besides, stakeholder interests might also change over time. This shows the importance of developing DH systems in such a way they are capable of adapting to new circumstances.

8.1. Description of current planning process

This section will investigate the way DH systems are currently planned, designed and developed and will dive deeper into the way planning processes are generally performed in Denmark and the Netherlands. The planning process of the Greater Copenhagen and Greater Amsterdam DH systems will be briefly discussed too.

8.1.1. Denmark and Greater Copenhagen

When the Heat Supply Act was established in 1979, after the oil crises during the past decade, the Danish DH sector got a boost. Many new DH systems were to be developed and expanded over the coming years in both small towns and large cities. To ensure an organised and economically efficient development of energy infrastructure an extensive heat planning framework was established as part of this new heat regulation.

In this new planning framework provincial authorities and – especially – municipalities were made the central players, although the national government would establish frameworks and set boundaries. Municipalities were made responsible for mapping heat demand and supply methods within their municipal boundaries, based on which provincial authorities could draft regional overviews, as can be seen in Figure 43. After this, a second step included municipalities drawing different heat supply options and provinces that summarised this for the municipalities within their territory. Finally, provincial heat plans prioritised different heat supply options per area and identified locations for (central) production units (Danish Energy Agency, 2017, p. 11). Municipal heat plans were based on their regional counterparts and designated which areas where to be supplied through either natural gas grids, DH grids or have an individual or small-scale, decentralised solution (Danish Energy Agency, 2015, pp. 10-11). As the last part of the planning process, a set of system requirements was established, based on which (potential) DH companies could formulate their proposal in the procurement process. With these system requirements, the design and development of systems in DH-areas could thus start.

In the years that followed, DH companies developed new systems and expanded current systems into new areas that were assigned as a DH-area in the heat planning process. Many DH companies were structured as consumer cooperatives, especially in smaller towns and cities. In the larger cities DH companies were also established by municipalities themselves. Whenever a DH system was to be developed, expanded or – for example – a production facility was changed, the DH company would draft a project proposal, as illustrated in step 4A or 5A of Figure 43. These project proposals were than evaluated by the municipality, based on a framework that was developed by the Danish Energy Agency and focused mainly on selecting the project alternative with the largest socio-economic benefits (Danish Energy Agency, 2015, pp. 10-12). This procedure is still in place, although the development of DH systems is not as rapid and substantial as before, as the DH sector is very mature today.

The planning process in Greater Copenhagen followed this procedure too, more or less. In Copenhagen and many municipalities around it, DH was assessed as an appropriate heating technology for the (dense) built environment. During and after the 1970's, many DH companies were established or were already present – both cooperatives and municipally-owned companies. As the companies were either owned by consumers or the municipality, many 'consuming' (or 'passive', see section 7.2) stakeholders were – and still are – represented in the DH company, either directly or indirectly. This involvement of citizens and other stakeholders really boosted societal support, together with the transparency of heating costs (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, pp. 17-18). However, this support was also necessary, as municipalities were given the possibility to impose and enforce an obligatory connection to DH systems for consumers. Many of them made use of this possibility, including the municipality of Copenhagen and although laws regarding these obligations have recently been loosened up, in many areas in (Greater) Copenhagen this obligation is still in place (Honoré, 2019).

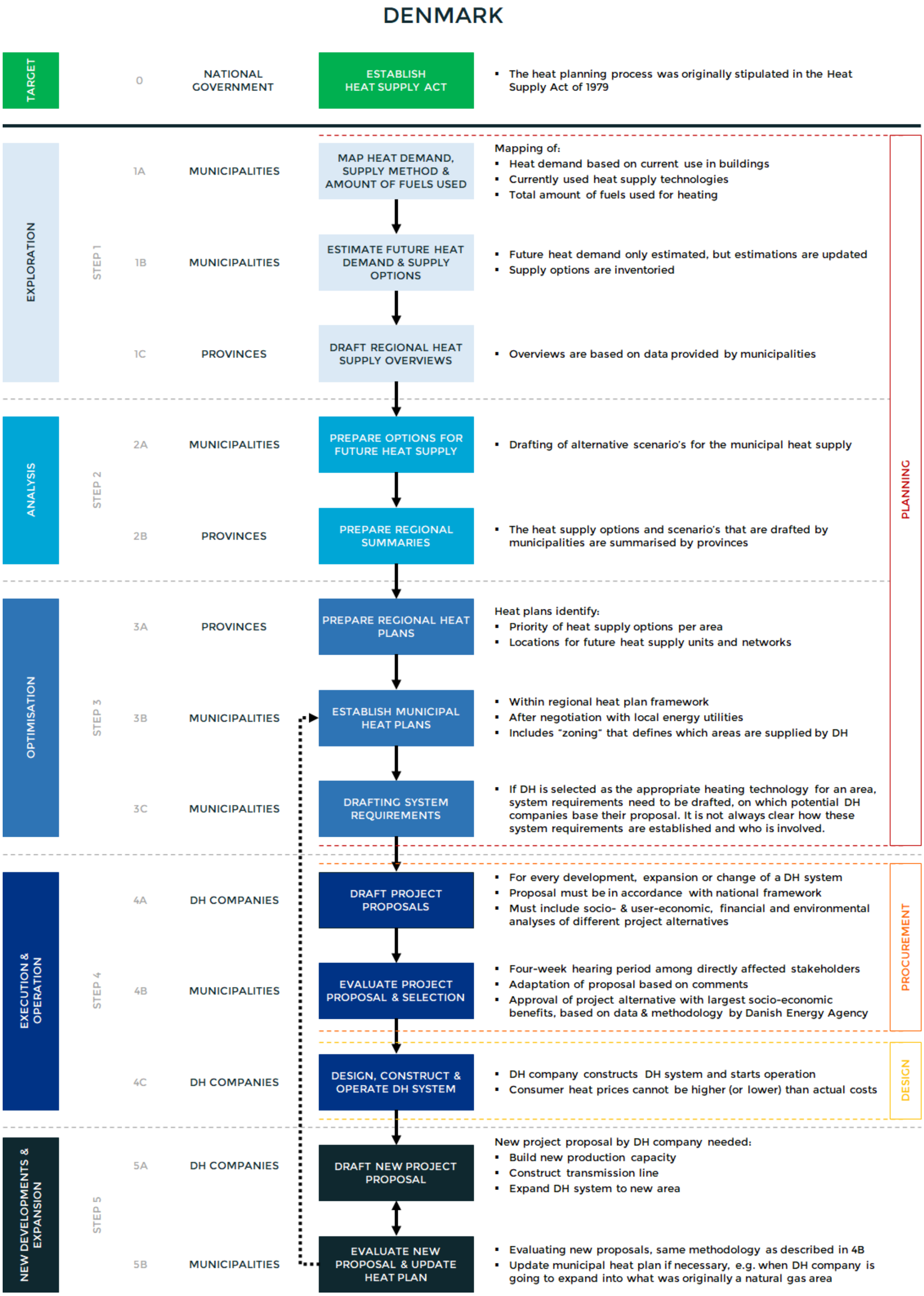


Figure 43 – The heat planning and subsequent DH system design process in Denmark, from the initial outline of the Heat Supply Act, via provincial and municipal heat plans, to the actual DH system design (own illustration)

8.1.2. The Netherlands and Greater Amsterdam

The Dutch DH sector has always been relatively small and has not been specifically stimulated or regulated. The planning process was therefore not prescribed or clearly specified by some kind of government policy and there was no national framework for planning for the DH system design and development. However, as the Dutch national government has agreed to reduce CO_2e-emissions by 49% in 2030 – compared to 1990 levels – and to abolish the use of natural gas from the built environment in 2050, DH is expected to be playing a vital role in this heat transition.

After the Dutch government reached a cross-sectoral *Climate Agreement* (Dutch: *Klimaatakkoord*), several policies, procedures and strategies were drafted in order to reach the goals that were agreed upon in the agreement. A number of those were focused on the built environment in general and/or the heat transition in particular. Together they illustrate the process in which a certain area will progress towards a sustainable heat provision by adopting an alternative heating technology. As can be seen in Figure 44, the Dutch municipalities will be the most important players in the heat transition and the process of establishing alternative heating technologies per neighbourhood, to replace natural gas use for heating and hot tap water.

After accepting the Climate Agreement, the Dutch government divided the country in 30 "Energy regions" that would be responsible for drafting regional energy strategies that focus on the electricity and built environment sectors in realising the Agreement's emission-targets. Besides these, the Netherlands Environmental Assessment Agency (PBL) drafted initial heat transition strategies for each neighbourhood in the country, which could then be supplemented with more specific local data by the municipalities. Analysing these first indications and discussing the results with local stakeholders in each area would provide municipalities with enough input to draft their municipal *Heat Transition Vision* (*Transitievisie Warmte*). Every Dutch municipality is required to have established their own heat transition vision by the end of 2021. For each area this vision should be translated into a *Neighbourhood Implementation Plan* (*Wijkuitvoeringsplan*). For some areas a DH system will be identified as the most appropriate technology, for others this might be via individual heat pumps or biogas distribution through the existing natural gas grid.

The steps described above only illustrate the process of selecting an alternative future heating technology though. They do not state anything on drafting system requirements or the design of the actual DH system itself. In fact, there is no common prescription or general instruction for these later phases of the planning process and design of DH systems and the way proposals of bidding companies are evaluated and selected by authorities. At the moment it is not even always clear whether or not procurement regulation applies and to what extent. Sometimes DH companies are directly and privately awarded a contract (Van Hest & Van Laar, 2019). Currently, the Ministry of Economic Affairs and Climate is working on a new Heat Act (*Warmtewet 2*) which is expected to take effect in 2022. This updated version of the previous Heat Act of 2013 should introduce clear rules on procurement procedures. However, it is not clear yet to what extent the new heat act will also introduce directives for the planning process and design of DH systems. Right now, the regular procedure would – at least in theory – be to draft system requirements, write out a tender, select a DH company from the available bids and start construction and operation of the system. In practice, this is not always the applied approach, especially when there already is a DH company present within the municipality. Moreover, which organisation is responsible for drafting requirements and who is involved in this process is also unclear.

When looking at the planning process of the DH system in Amsterdam, this same impression is given. Both parts of the system were initiated by public companies – UNA in the Southeast and GEB Amsterdam / WPW in the Northwest – and both had the objective to make use of surplus heat, from electricity production and waste incineration respectively. There was no public tendering procedure or elaborate discussion within this process. In later expansions into new districts certain procurement procedures were indeed followed initially, although these sometimes still resulted in failed tendering and consequentially a direct awarding nevertheless (Buijck, 2019).

Within the heat transition that the municipality of Amsterdam is currently going through, it still is the question how much different future planning processes will be in practice. As the city has two quite large and soon connected integrated DH systems and the municipality has very high ambitions – it aims to be *"natural gas free"* in 2040, ten years before the national target – the city government wants to accelerate the heat transition and plans to connect over half of all HEQ's to a DH system. Over 350,000 HEQ's are expected to be connected to a high-temperature DH system, like the current two systems of Vattenfall. With very little competitors in the Amsterdam DH market, especially of the size of Vattenfall, it therefore remains to be seen whether there will be a very competitive procurement process, even when a public tender is issued. It is also questionable to what extent different options for a DH system design – both physical and organisational design – will be considered and whether the system design will be tailored towards the interests of local stakeholders in every area.

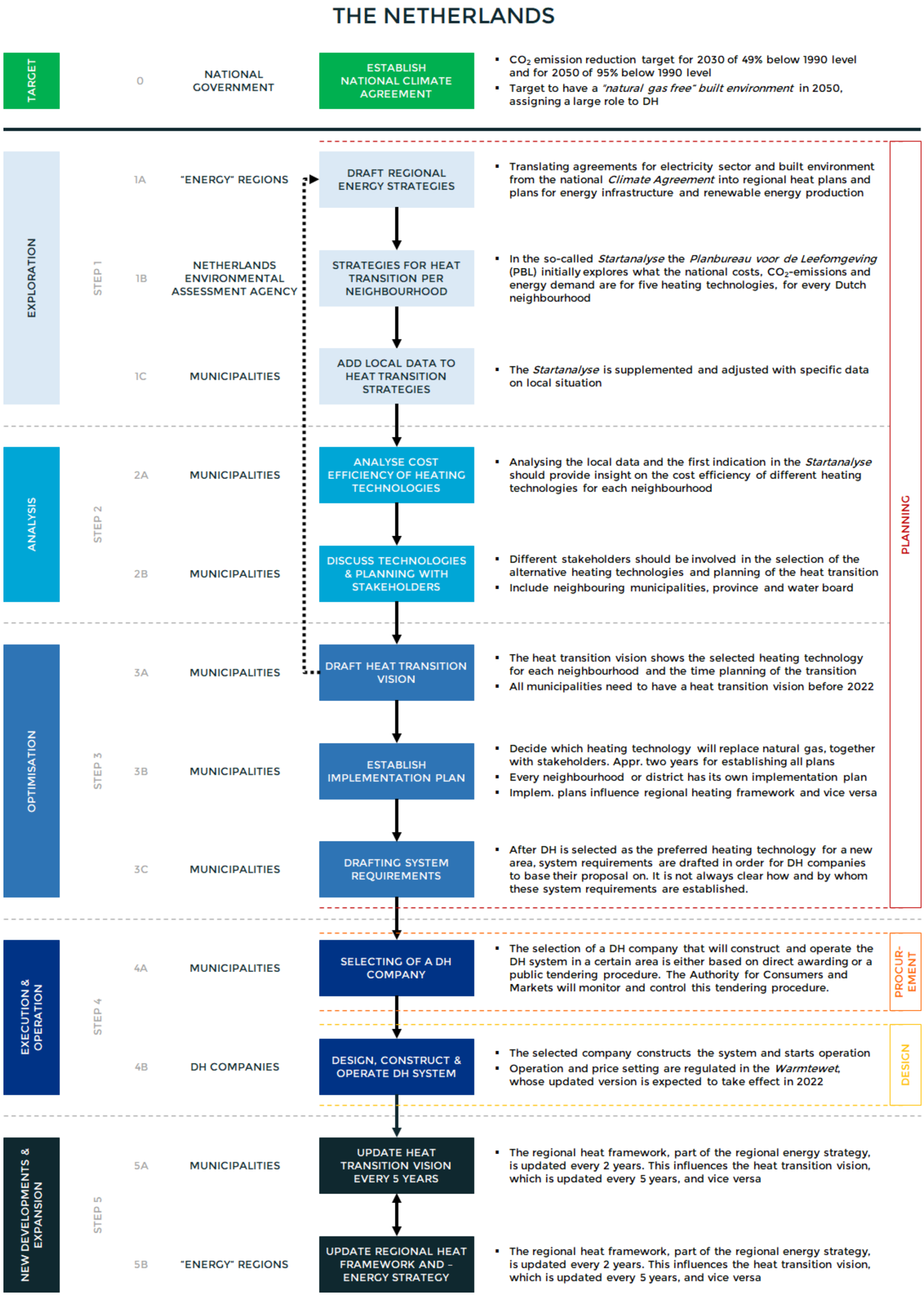


Figure 44 – The heat planning and subsequent DH system design process in the Netherlands, from the initial outline of the Climate Agreement, via regional and municipal heat plans, to the actual DH system design (own illustration)

8.1.3. Comparison

In both the Greater Copenhagen and Greater Amsterdam area there is a centrally organised, top-down heat planning process, from the national level, via provinces or regions to the municipal level. In both countries municipalities fulfil a central role in this planning process and are ultimately responsible for coordinating the DH system design in areas that are designated to become DH areas. However, in Denmark this coherent heat planning process was already established in the 1970's. In the Netherlands natural gas grids were developed around that same time and only in recent years a heat planning framework is set up that actually aims to more away from natural gas use for the built environment.

The Copenhagen and Amsterdam systems were developed many years ago, although in Copenhagen this was already in the first half of the 20th century and in Amsterdam this was only in the 1990's. In both cities DH was initially established by municipal companies, but in Amsterdam these were later privatised and in Copenhagen they still are (mainly) municipally-owned. This is also the reason that citizens and other stakeholders are more directly represented and sometimes also involved in the planning process in Copenhagen, compared to Amsterdam. The heat planning procedures in these countries both aim to include all stakeholders into the process of heat planning, but representation and especially stronger inclusion of stakeholders in the planning process seems much more limited in Amsterdam than in Copenhagen, mainly due to a lack of direct involvement and a different ownership structure of DH companies. This is especially visible in the process of drafting a set of system requirements – a key part of the planning process, as it constitutes the end of the process, just before the procurement process and subsequent design process will further build on these system requirements, as is illustrated through steps 3C and 4A in Figure 43 and Figure 44. The fact it is quite unclear how stakeholder interests are translated to and incorporated in system requirements (like is explained in chapters 6 and 7), based on which tenders and the ultimate system design are established, is an important weakness of heat planning in both countries.

8.2. Inclusion of stakeholder interests in planning and requirements

The way and extent to which stakeholders are involved in the planning process of a DH system also defines the way stakeholder interests are prioritised. It is important to understand how stakeholders are represented and/or included in the planning and design of the DH system and how their interests are weighed and by whom, as this to a large degree determines which system requirements are considered and eventually incorporated in the system design. As is shown in chapters 6 and 7, stakeholder interests and the requirements that arise from those can vary significantly between stakeholder types. The degree to which these stakeholder can influence the last steps in the planning process – the drafting of system requirements – determines to what extent their interests are promoted and ultimately met by the DH system design.

8.2.1. Greater Copenhagen

The Danish Heat Supply Act provides rules and structure to the heat planning process. This heat planning was organised relatively top-down, although citizens and other stakeholders were, for example, involved through public consultation and discussion sessions. When looking at the end of the planning process – so after a DH company is assigned to establish a DH system – the involvement of stakeholders is structured similarly. Near the end of the heat planning process potential DH companies draft project proposals for grid extension or new production facilities. Then, municipalities evaluate different proposals and eventually select one proposal, based on a socio-economic cost-benefit analysis, in which societal interests are already looked after, although focus is on economic optimisation. Lastly, there is a four-week hearing period among affected stakeholders. In practice other stakeholders than the DH company and the municipality are only involved after a proposal is already initially approved. Comments and suggestions that come out of these hearing processes do not necessarily have to be adopted, though.

As stakeholders are not very directly involved in the planning of (parts of) their DH system, they cannot make their interests be heard directly. However, because all DH systems in GC are owned by (groups of) municipalities or consumer cooperatives, there is a very strong indirect representation of stakeholders and their interests are promoted through their share in the DH company's ownership structure and governance. This way stakeholders such as individual consumers, housing associations, private building owners and commercial companies have secured their interests even though they do not have direct control over the system's design. The way their interests are prioritised is twofold:

1. **Each stakeholder prioritises its interests individually;** for example: whether the affordability or the sustainability of the heat supply is more important to a housing association is internally discussed and decided upon, within the HA's own organisational and governance structure;

2. **All stakeholders and stakeholder types together prioritise their interests;** a HA may have different interests than a municipal swimming pool or commercial building owner. They have to collectively decide upon prioritisation of these interests, where their individual influence depends on their size in terms of total consumption and/or number/size of connections. Within cooperative DH companies this discussion and prioritisation is organised more directly than in municipal companies, but in both cases all stakeholders are represented.

8.2.2. Greater Amsterdam

Originally the DH systems in Amsterdam were also developed by publicly owned companies, but these companies were later unbundled and privatised. Currently, as Amsterdam stands on the thresholds of one of the largest transitions and renovations the city has seen, these systems play an important role in the municipal energy strategy. In their *Heat Transition Vision*, the municipality estimates that roughly 440,000 HEQ will be connected to DH in 2040, even 590,000 HEQ when VLT 'bronnetten' (see section 5.1.2.3) are included. Over 350,000 HEQ will be connected to a HT (70°C) DH system in 2040 (Geldhof, Nieuwenhuis, Oudejans, & Smoor, 2020, p. 19). Of these 350,000 a rough 100,000 are already connected to the HT systems of WPW and Vattenfall. The question is what the role of the two existing DH systems will be in this expansion. But also what influence WPW and Vattenfall thus have in the design of the systems in the future Amsterdam DH sector and to what extent other stakeholders are included in the planning process.

At the moment many stakeholders are not very involved in the design and operation of the DH system they are or will be connected to. When a new area is supposed to become connected to a DH system, the municipality is in charge of coordinating this process and eventually awarding the contract to a DH company. However, currently procurement regulation is not always clear and rules around direct, private awarding of contracts leave room for interpretation. It is therefore not always transparent how DH developments are performed and completed.

Furthermore, there is no clear procedure on including stakeholders and incorporating their interests in the system design. There are no formal frameworks that enforce or even require involvement of stakeholders in the establishment of system requirements and incorporation of their interests in the subsequent design process. There also seems to be very little competition on the DH market, too little to stimulate a DH company to adjust the system's design to meet stakeholders' needs. In fact, the evaluation criteria based on which a municipality awards a DH company the contract do not necessarily include criteria for stakeholder involvement. As the Amsterdam DH systems are mainly privately owned (Vattenfall owns 100% of SE system and 50% of WPW system), there is also no indirect representation and stakeholder interests are not promoted through their shared ownership of the DH company. Only the 50% stake of the municipality of Amsterdam in the WPW grid guarantees an indirect seat at the table for affected stakeholders.

There are several initiatives with ambitions for cooperatively-owned DH systems, both in Amsterdam and the GA area, although these will not be realised for a while. There is also a large, 100% municipally-owned DH system in the city of Purmerend. This is also the city with – by far – the highest market share for DH in the Netherlands, with a rough 75% of HEQ connected to DH. Within SVP, the DH company of Purmerend, consumers are not directly involved but indirectly represented by the municipality.

8.2.3. Comparison

In both Greater Copenhagen and Greater Amsterdam the heat planning process leaves some room for involvement of stakeholders, although not too elaborately and not equally for all stakeholder types. Especially the 'passive' stakeholder types, as discussed in chapter 7, are not properly included. Given the fact that the passive stakeholder types are almost always all present, in contrast to the active stakeholder types, the disbalance between interests and influence is present in both Copenhagen and Amsterdam. Through public consultation sessions passive stakeholders can discuss and respond to heat plans and transition visions. However, in both cases stakeholder types other than the 'passive' municipality and the 'active' DH companies are largely left out of the planning process of the actual DH system itself. In Copenhagen they can only comment on or ultimately object to an already preliminarily approved project proposal by a DH company. In Amsterdam they are not involved in drafting system requirement either and stakeholders only have the legal right to object to issued permits.

Still, there are differences. In the Greater Copenhagen area, all DH systems are either publicly or cooperatively owned; except for several large production facilities, all transmission and distribution grids, heat delivery and many (peak load) heat sources are owned and operated by public organisations. By contrast, in Greater Amsterdam the majority of DH ownership lies with private owners, of which Vattenfall is by far the largest. This difference explains why stakeholders in Greater Copenhagen see their interests promoted and ensured through this public ownership, either directly in cooperatives or indirectly in municipal DH companies and in both the planning process and later operation of the system. In Greater Amsterdam stakeholders see there is no clear procedure or formal framework that stimulates direct incorporation of their interests into the planning and subsequent system design. The reason public support for DH systems is still quite strong in Greater Copenhagen thus appears to be not only due to the fact that DH has a long history, competitive and cost-based tariffs and transparent operations, but also because practically all of these companies are owned by consumers or municipalities and interests of the 'passive' stakeholder types are therefore better represented.

8.3. Adaptability of system design

In many European countries DH is either an important sector in the energy industry, or will develop to be a significant, full-grown market in the coming years. Consequently, the role DH is going to play in the European energy transition is considered large. Therefore, especially because of the fact the European energy supply will go through a transition, it is important DH systems are able to adapt to changing circumstances.

The energy transition inherently involves large changes. Furthermore, the energy transition is not a simple project with a start- and end-date, but is a very long process that brings uncertainties and new developments. On the other hand, the energy transition cannot wait until everything is settled and fully developed. DH systems should therefore be able to adapt to these changes, mainly on the following aspects:

- Changing problems;
- Developing interests and preferences;
- New technologies
- Transforming scale
- Coupling of systems

Then, the question rises to what extent current systems are able to do this and how this ability is incorporated into the planning process of future systems. It is therefore necessary to include this adaptability into the analysis of the planning process.

8.3.1. Greater Copenhagen

The Greater Copenhagen DH system is one of the largest in the world. It is therefore not surprising it plays an important role in the climate goals of the city of Copenhagen, including the ambition to become the "first carbon neutral capital in the world". This leads to the municipality aiming to have a carbon neutral DH system as well. In order to realise this ambition fossil fuels for heat production are being replaced, mainly by biomass. However, biomass is also seen – by DH companies and municipalities – as a 'transition fuel' towards a fully sustainable heat provision and is anticipated to also be replaced in the long term (Holm, 2019) (Honoré, 2019) (Nimb & Danekilde, 2019). Sources that are expected to be used in the farther future include electrical heat pumps, solar thermal plants, surplus heat and, especially, geothermal energy (Holm, 2019) (Honoré, 2019). But many people have their doubts on how the GC DH system is going to move away from biomass again, also because large new investments have to be made now in order to shift from fossil fuels (mainly coal) to biomass. These investments are expected to create a lock-in, like the large CHP-plants are regarded to do already (Nimb & Danekilde, 2019). A transition towards more decentralised production is also foreseen by many people, but the same lock-ins by large CHP- and waste incineration plants are considered to be a barrier towards decentralisation. This decentralisation is considered to be necessary to tap into new and more sustainable energy sources (Holm, 2019) and is thought to be accompanied by a shift towards lower temperatures in the DH system (Honoré, 2019).

The expectations described above are a few of the many possible developments, changes and transitions that could be possible. Besides, these are the uncertainties for the very large and mature DH system of GC, not for a small, new or rapidly developing system. The question is to what extent the system and the planning process leave room for adaptability. This ability to adapt is discussed via the three expected transitions that were mentioned.

Biomass as transition fuel

In light of the high ambitions of the municipality of Copenhagen, the CO_2e-emissions of heat production for DH needed to be lowered drastically and fast. Through different subsidies and fiscal advantages (see section 5.1.1.4) the national government has ways to heavily stimulate biomass. The GC DH system can therefore quite easily adapt to the carbon ambitions of the municipality, as stimulation of fuels that are considered carbon neutral is easy. Through their ownership of many DH transmission and distribution companies, municipalities can execute their own climate ambitions by retrofitting or replacing their (peak load) production facilities. The DH system design framework ensures this is done in the most cost-efficient way, because of the requirement of a socio-economic cost-benefit analysis of DH project proposals. Furthermore, production and transmission/distribution are (partially) unbundled, with a large share of baseload production being covered by Ørsted. Because Ørsted has no DH grids of its own, it is dependent on the municipal transmission grids in order to sell the heat it produces. This relationship also creates a stronger negotiating position to achieve municipal ambitions by shifting towards biomass. However, the very high investments in these large CHP-plants in general and new biomass retrofits in particular create a lock-in because of which the move away from biomass in the farther future could be harder to realise. With 70% of heat production in the GC system coming from 4 large CHP-plants, this makes CHP-plants and the DH system highly interdependent.

Decentralisation of heat production

In order to shift away from biomass, heat production is expected to become decentralised, as more smaller, low-temperature sustainable heat sources will be connected. However, the existing large CHP-plants are considered to create a lock-in, as stated above, because of their high investment costs. By shifting towards decentral heat production too fast and easily the business case of these plants will deteriorate or even collapse, leading to high costs for society. Even though heat production and DH grid are largely unbundled, the major share of these plants in baseload production enforces the dependency on these sources. Besides, two large waste incinerators also cover a significant share of heat production, leaving only 5% of total current heat production for small, decentralised sources. The only significant existing decentral sources are the various peak load plants. These are not only hardly used and not very efficient, they are also often natural gas-, biomass- or oil-fired boilers that thus not qualify as useful sources in the transition away from fossil fuels and biomass. On the positive side: the current GC system, consisting of about 20 distribution systems and two large transmission systems, could form a beneficial structure – both physically and organisationally – to steadily develop more sustainable local sources, while having the security of supply of the larger network. Still, in order to be able to provide this security during this transition, the integrated system probably still needs larger baseload plants. The business cases of both the developing small decentralised sources and existing large centralised plants are frustrating each other, hence there is only one small industrial surplus heat provider within the entire system. There size of the interconnected system could allow for a phased transition towards decentralised renewable sources via stepwise development of new sources.

Conversion to lower temperatures

Lowering the temperature level in the GC system is considered necessary in order to be able to connect a more diverse range of production facilities with lower feed-in temperatures (Honoré, 2019). Lower forward temperatures are also beneficial as they reduce heat losses in transmission and distribution. The current relatively high temperatures are a challenge to (potentially) renewable sources like heat pumps. When expanding the DH system into areas with newly constructed buildings the system could operate on a lower temperature, creating the opportunity to establish sources like heat pumps. However, the current distribution systems are highly connected through the vast transmission grid. As this grid operates on a certain temperature level and all distribution systems are supplied with heat through the transmission grid, it is not easy to differentiate temperatures between distribution systems. Lowering the temperature level for the heat transfer in exchange stations between transmission and distribution grids could be an option, although this might reduce efficiency. Cascading or connecting one of the distribution grids on the (lower temperature) return pipe of the transmission system could also help reduce temperature levels, but is not always possible and/or efficient, as the existing building stock might require a high temperature due to poor insulation. Lastly, the organisational structure in which every distribution system has its own municipal or cooperative owner might be difficult in adjusting the temperature levels of different grids to each other. On the other hand, this ownership structure could also help in optimising the distribution system design to the interests of local stakeholders. Moreover, all municipalities with a DH system that is connected to the transmission grid together share ownership of the transmission company; a structure through which consensus could be found on temperature levels in the GC system.

Lastly, when looking at the role of the project proposal in the planning process, the question could be raised whether an evaluation of the proposal on a pure project level is an adequate way to enhance adaptability of the system as a whole. For this, the impact of the proposed project on the complete system should also be evaluated, although this might be hard to realise in practice. The ability of the proposed project itself to adapt to changing circumstances could also be an appropriate criteria in the evaluation of proposals.

8.3.2. Greater Amsterdam

In Greater Amsterdam, there are several DH systems that are not connected and operate independently. Only the two large DH systems in the municipality of Amsterdam will soon be connected. When examining the great climate ambitions of the city of Amsterdam and the large role that is foreseen for DH, the current systems in Amsterdam will have an important position in the city's heat transition. Whether or not the existing DH systems will be expanded and to what extent new systems will be developed remains to be seen. Besides, a lot depends on the ability of current and new systems to adapt to changing needs and technologies in the coming decades.

Both the north-western and south-eastern part of the Amsterdam system are (mainly) supplied by one production facility; the AEB waste incinerator in the northwest and the Diemen CHP-plant in the southeast. The dependency on these plants is twofold: they cover the majority of heat supply and they form the main reason for the high temperature level in both systems, with between 120°C/95°C feed-in temperature at the source to 70°C delivery temperature at the end-user (Buijck, 2019) (Van Zanten, 2019). In the southeast (SE) system Vattenfall is the (only) vertically integrated DH company, in the northwest (WPW) system Westpoort Warmte is the distribution company, with AEB as the main producer and Vattenfall as provider. Especially in the SE system the organisational structure makes Vattenfall very influential. This structure also seems to provide an incentive to, for example, adapt the operation of the distribution system to the characteristics of the Diemen CHP-plant, instead of to the interests of other stakeholders in this distribution system. There is no formalised way stakeholders can have a say in the system's operation or participate in the process towards a future design. In the WPW system the municipality of Amsterdam is partially involved through their 50% ownership. However, even though other stakeholders are at least represented by the municipality, there is no formalised procedure for stakeholder involvement either.

The extent to which the system is able to adapt to changing circumstances seems to be limited. Both on the physical side, given the strong dependency on the two main heat sources and the alignment of production and distribution temperature levels, and on the organisational side, because of the strong influence of and large incentives for Vattenfall in tuning the system's design to their individual (private) interests. Especially because of the recent developments around AEB, possible privatisation of the waste incinerator and sale of the municipal share in WPW – possibly to Vattenfall – the influence of the municipality might diminish (McDonald, 2020). This way there is less organisational pressure to adapt to changing ambitions and interests, or to adjust the system operations (e.g. temperature) or sources (e.g. natural gas CHP) to the targets of the heat transition.

On the physical side, adaptation of the system to changed interests could also be enforced through subsidies, taxes or even legal measures. However, when there is only one party active within the DH system that needs to adapt, competitive pressure and innovation capacity are probably lower than in a system where several parties operate. This might lead to the system adapting to changes, but for higher costs than would have been made with more competitive pressure and innovative capacity. The ability to adapt could then be considered lower for a monopolised DH system. On the other hand, the integration of roles within the system could make it easier to adjust different system components to each other in gradually adapting to changes. Still, this could also be limited because of incentives to protect (private) interests in one of these system components.

Looking at the planning process, there seem to be no formal criteria for evaluating tender bids on their ability to adapt. There are also no clear procedures or guidelines for involvement of (other) stakeholders, which could help to have a broader view on different (future) interests and come up with a widely supported system design. In the planning process for the heat transition there is a strong focus on translating regional and municipal heat plans to implementation plans on the neighbourhood scale. Fortunately, there is some focus on alignment between different neighbourhood implementation plans, but this seems to be directed more towards calibrating the phasing of different construction activities. A stronger focus on the ability to adapt and alignment of the collective of DH systems, even when currently not coupled, could be beneficial to later changes and the potential to connect different systems.

8.3.3. Comparison

Even though the Greater Copenhagen and Greater Amsterdam DH systems are in very different states of development and maturity, both are facing rigorous transitions in the coming decades. The ability to adapt to the expected changes depends on both their physical and their organisational design. In Copenhagen, the system is very large and interconnected and is depending on a handful of large CHP and waste incineration plants. Its ability to adapt to climate ambitions and new technologies strongly relates to the dependency on these plants, as (financial) lock-ins and security of supply prevent rapid adaptation by substituting these plants with new technologies. The same can be seen in

Amsterdam, where a smaller system is also largely dependent on two plants for heat production and a lock-in is created.

The difference between Copenhagen and Amsterdam mainly is in the fact that the GC system knows partial unbundling between production and transmission and the (public) ownership structure of all transmission and distribution systems. Because of the partial unbundling, transmission and distribution systems have lower incentives to not adapt when this harms the business case of production facilities they do not own, although they still are dependent and cannot not act too drastically. The ownership structure ensures that changing societal interests or climate ambitions are represented directly and indirectly via the strong influence of transmission and distribution companies (the latter also covering delivery). In the Amsterdam systems both unbundling (of production) and ownership are organised differently. The vertical integration creates incentives for protection of the interest in and business case of production facilities, even when that implies not adapting properly to changing circumstances. The mainly private ownership structure leads to a weak representation of and adaptation to societal goals and (other) stakeholders' interests. Lastly, in both the GC and GA case there seems room for improvement on the incorporation of criteria for adaptability of the system design and its components to future developments.

8.4. Conclusion

There are differences and similarities between planning processes of DH systems in various metropolitan areas and countries. Describing and analysing these processes not only increases understanding of the way DH systems are formed, but also of the way stakeholder interests are incorporated and prioritised, to what extent systems are made able to adapt to future changes and what challenges the planning process and resulting system design encompass. This chapter provides an answer to the issues above and, as a result, to the third sub-question.

SQ3	How are district heating systems currently planned by stakeholders in metropolitan areas and what are the main challenges?

Where the first steps in the heat planning process are relatively top-down – from the national to the local level – this is not the case for the later phases of the planning process. In both Denmark and the Netherlands municipalities are responsible for these steps of heat planning and the local implementation. In the Copenhagen and Amsterdam areas municipalities were the first to develop DH systems over the last decades, but in Amsterdam these were later privatised. Municipal or cooperative ownership is also a main reason stakeholders are better represented in the planning (and design) process and the operation of the system in Copenhagen, although direct involvement of all stakeholders in the planning process is limited in both countries.

Many stakeholder types are only involved in the process of heat planning through public consultation sessions where they can respond to and discuss heat plans. In the later phases of the planning process, especially considering the establishment of system requirements, especially the 'passive' stakeholder types are not involved. Whether their individual interests are heard and promoted mainly depends on the ownership structure of the DH company. In Copenhagen, stakeholders like housing associations, commercial companies and individual consumers – and their interests – are represented either directly or indirectly through cooperative or municipal ownership respectively. In Amsterdam only the municipal 50% share in one half of the system ensures some representation of these passive stakeholder types and their interests.

Both Denmark and the Netherlands will go through an intensive energy transition, as many European countries will. The ability of their DH systems to adapt to changing circumstances is therefore very important. However, in both Copenhagen and Amsterdam this ability is limited, due to both physical and organisational barriers. In Copenhagen the ability to adapt strongly relates to the dependency on large CHP- and waste plants, as (financial) lock-ins and maintaining security of supply prevent rapid adaptation through substitution. The organisational design stimulates this ability more, as partial unbundling and the public ownership structure lower unwanted incentives and ensure that changing societal interests and ambitions are represented. In contrast, in Amsterdam there are both a dependency on two large-scale, high temperature heat sources and the integrated private ownership of most of the two DH systems that make that the current system is expected to be poorly adaptable to developments in the energy transition.

9

SYSTEM DESIGN TYPES

Three-step design type identification & relation to requirements

AEB's waste incineration plant, Amsterdam

Before understanding how the planning process and the design of DH systems in metropolitan areas can support stakeholders in their transition towards a sustainable heat provision, it is important to find out what possible system design types there actually are and how they relate to the stakeholder interests and system requirements. This chapter will do exactly that, by answering the fourth sub-question.

SQ4	What are possible district heating system design types and how do these relate to stakeholder interests and system requirements?

To provide an answer to this question, this chapter is divided into three sections. The first will determine which factors in DH system functioning, as described in section 3.2, can be considered system design factors and thus to be influencing the DH system's design. The second section will identify different system design types, based on the selected factors of the first section. The third and last section will go into the relationship between these system design types and the requirements that were described in section 7.2.

9.1. System design factors

This chapter will describe what DH system design types can be distinguished and how these relate to stakeholders interests and system requirements. First, this section will determine which factors in DH system functioning are considered factors that influence a DH system's design. In order to do this, the factors that were described in section 3.2 are reviewed. These sixteen factors are spread over four categories: *technical and physical factors*, *regulatory and policy factors*, *economic factors* and *societal factors*.

First the concept of 'system design' is examined. There are different layers to the design of a DH system. There is the physical or technical layer, that defines how the system is constructed, operated and maintained, where the thermal energy is produced, how the heat is distributed and in what kind of environment the system is situated. There also is an organisational layer, which tells something about the type of organisation that is – or organisations that are – active within that system, what kind of roles are fulfilled and by whom, how decisions are made and whose interests are represented in the heat planning process. And there is the question whether a heating system can be considered a "district" heating system in the first place. This last question is not considered to be covering the system design, but merely if a system is part of the scope of this research. This could be depending on whether a system is actually distributing heat throughout a 'district', or whether it is a collective infrastructure instead of an individual facility.

When looking again at the sixteen factors of section 3.2, it needs to be determined which of these factors relate to the question if a heating system is a DH system or not, which factors relate to the technical design and which factors relate to the organisational design, as described above. Of course, it is also possible that some factors will not relate to any of the above. The factors that are considered as system design factors will be included in the identification of system design types in the next section.

System design factors are not limited to one of the four categories that were used in section 3.2. As explained above, a system design involves not only a technical part, but also an organisational design. For example; factors that were initially included in the regulatory or economic category might therefore also be included in the system's (organisational) design. Others might not. When looking more closely at the sixteen factors, there are three factors that could help answer the first question and determine if a heating system is DH system or a 'regular' heating system; the *number of connections* and the *energy supplied*, both part of the *system size* factor, and the *role distribution*, in terms of integration of the role of consumer with the role of DSO. The number of connections – and actually more specifically the number of consumers, both private and organisational – tells something about the size of the system and goes beyond the number of connected buildings, which might be all used by one consumer. The (total) energy supplied is mainly an indication of the size of the system. The distribution or allocation of the roles of consumer and DSO tells whether a consumer operates its own, private system to which other consumers cannot connect.

The second step is the one of the technical design. Although there are several factors in the *technical and physical factors* category, only two are considered to be both very important to the system's design and having a large variation in possible outcomes; the factors of *temperature regime* and *type of heat source*. There are quite some differences in forward and return temperatures in DH systems and in diversity of heat sources, even though many systems show similarities. Besides, these factors are considered very relevant to a system's functioning.

The third step treats the organisational design. This is a very broad concept and many factors might influence the organisation of a DH system. In order to be able to identify useable organisational design types, only the most relevant factors will be selected. Three factors are selected: *unbundling*, *third-party access* and *ownership*. These factors are considered to illustrate what type of organisations are active within the system, what roles they fulfil, how and based on what they make decisions and how stakeholders are represented.

Some of the sixteen factors are not considered to influence the system design and thus not included as system design factors. These factors either are regulatory and policy framework factors that together determine the legislative framework a government establishes around the DH sector, or boundary conditions for which a minimum value needs to be achieved. In Table 9 these factors are shown. The only factor that is not included in any of the above groups is the factor *integration of energy systems*. This would be considered a technical factor, but is simply not relevant and differentiating enough and therefore not included.

FACTORS IN DH SYSTEM FUNCTIONING		
SYSTEM DESIGN FACTORS	**REGULATORY & POLICY FRAMEWORK FACTORS**	**BOUNDARY CONDITIONS**
System size – *number of connections*	Price regulation	Heat demand density
System size – *energy supplied*	Obligatory connection	
Role distribution	Planning	
Temperature regime	Citizen participation	
Type of heat source	Consumer representation	
Unbundling	Transparency	
Third-party access		
Ownership		

Table 9 – The fifteen factors that were identified in section 3.2 are divided in three categories, of which the "system design factors" category is important in identifying system design types in section 9.2

9.2. Identification of system design types

Identifying system types can improve understanding of the many different shapes a DH system can have and what those mean for the system's functioning. As there are countless variations and numerous properties for DH systems, this identification of system design types will be divided in three steps, using the system design factors that were described in the previous section:

1. **District and other heating systems;** what exactly is a DH system and what is not?
2. **Technical design types;** what physical and technical variations can be distinguished?
3. **Organisational design types;** in what ways can DH systems be organised?

In principle every DH heating system can be categorised, through these three steps, based on its physical dimensions, technical characteristics and organisational structure.

9.2.1. District and other heating systems

In order to identify different system types it has to be very clear what the exact definition and scope of a *"district heating system"* is. What exactly is considered to be a DH system and what is 'just' a heating system? There are so many different systems that provide heating to buildings, but not all are considered to be DH systems. Still, the use of the expression of *"district heating"*, *"fjernvarme"* (Danish) or *"warmtenet"* (Dutch) often refers to very different systems. Confusion also seems to result from etymological differences in the wording of the concept of DH in various languages and what variations may exist in what is understood of this concept. Especially when discussed in reports, popular media and the public debate in the Netherlands the word for district heating system – *warmtenet* – often seems to have a wider scope than the English expression *district heating*. This identification step will determine whether or not a heating system can be considered a DH system.

Three system design factors influence the definition of a DH system.

1. **System size – *number of connections*;** is there only one consumer, or are multiple consumers connected to the heating system? When more than one building is connected to the DH system, that does not necessarily mean this also includes more than one consumer. A housing corporation or an industrial company might be the only consumer, although different residential buildings of that HA or several facilities operated by the industrial company may be connected. However, in those cases there is still only one consumer.
2. **System size – *energy supplied*;** what is the system's total annual heat supply, in TJ/a? The total heat supply to all connections of the system gives a good impression of the size of the system.
3. **Role distribution;** How are the roles of Consumer, DSO and TSO distributed? In some cases, the consumer itself operates the heating system. It could operate its own heat source, heat distribution system and execute the delivery to its own building(s). This could range from a large gas-fired boiler in an apartment building, all owned and operated by a housing association, to an industrial estate where a company produces and distributes heat to supply to its own paper mill. In other cases the distribution (and perhaps production) of heat is outsources to another party, so Consumer and DSO are separated into two organisations. Even the roles of TSO and DSO could be divided over two separate organisations.

These three design factors are included in the *heating system definition framework* that is illustrated in Table 10 on the next page.

DISTRIBUTION	SYSTEM DIMENSIONS					
	One consumer			Multiple consumers		
	system < 150 TJ/a	*150 TJ/a < system < 1,500 TJ/a*	*1,500 TJ/a < system*	*system < 150 TJ/a*	*150 TJ/a < system < 1,500 TJ/a*	*1,500 TJ/a < system*
Only one party	**1**	**2**	3	10	11	12
DSO + Consumer(s)	**4**	**5**	6	**13**	**14**	**15**
TSO + DSO + Consumer(s)	7	8	9	16	**17**	**18**

Table 10 – The first step distinguishes 'regular' heating systems from DH systems, based on three system design factors

When looking at Table 10, it quickly becomes clear that there is a number of combinations of these three design factors that is either not very likely to occur, or not even possible at all. For example having a separate TSO and DSO in a system that is 'smaller' than 150 TJ/a is not too likely. Or having multiple consumers connected to a heating system and at the same time having only one party in that entire system is – by definition – not possible. To provide some more insight on the differences between DH systems and 'regular' heating systems several examples are given in Table 11.

HEATING SYSTEMS	
SYSTEM TYPE	**EXAMPLE**
1	Housing corporation that owns and operates a gas-fired boiler in its own apartment building (block heating), or Commercial company that owns its HQ-building and also owns and operates the ATES system it uses
2	Industrial company with its own heating system, for use in e.g. a chemical process
3	*Unrealistic combination of role distribution and size*
4	Hospital that outsourced the heating system it uses to a specialised company
5	Industrial company with different buildings or plants, that directly receive heat from another industrial company that operates both the heat source and the distribution system
6	*Unrealistic combination of role distribution and size; only one party that consumes over 1.5 PJ*
7	*Unrealistic combination of role distribution and size; separate TSO and DSO for relatively small system*
8	*Unrealistic combination of role distribution and size; separate TSO and DSO for medium-sized system with only one consumer*
9	*Unrealistic combination of role distribution and size; only one party that consumes over 1.5 PJ*
10	*Impossible to have all roles in one party & multiple consumers at same time*
11	*Impossible to have all roles in one party & multiple consumers at same time*
12	*Impossible to have all roles in one party & multiple consumers at same time*
13	**Small to average DH system in village, town or city district, that is operated by one single DH company that fulfils the role of DSO. Example: new DH system in Zaanstad, within the GA area**
14	**Medium-sized to relatively large DH system in a city, operated by a single DH company that is also the DSO. Example: WPW system in the GA area**
15	**Large to very large DH system that covers significant part of a metropolitan area and operated by one single DH company as DSO. Example: the integrated WPW- and SE-systems in GA, but only in the case AEB sells shares in WPW to Vattenfall**
16	*Unrealistic combination of role distribution and size; separate TSO and DSO for relatively small system*
17	**Medium-sized to relatively large DH system, operated by two or more DH companies that separate the roles of DSO and TSO. Example: DH system in Nijmegen, where Vattenfall is DSO and Provider and a separate party fulfils the role of TSO**
18	**Large to very large DH system, in which the roles of DSO(s) and TSO are separated and fulfilled by two or more organisations. Example: the GC DH system, in which two separate TSO's are active and roughly 20 DH companies fulfil the role of DSO's**

Table 11 – Examples for each of the 18 combinations that can be made in Table 10, showing which combinations are simply not possible (grey), which are considered only a 'regular' heating system (red) and which are considered a DH system (blue)

As can be seen in Table 11, on the previous page, there are several combinations of these three design factors that are not realistic or even possible. Of the nine remaining possibilities four types are not regarded as DH systems, at least for the purpose of this study. The most important reason these heating system types are excluded is because they only supply one consumer and are therefore both not considered to be collective systems and are expected to be specifically modified to the needs of that single consumer.

The other five possibilities are all considered to be DH systems, although there are differences. These types mainly vary in terms of size; some supply only a few TJ of heat per year, others might deliver over 10 PJ or 20 PJ to connected consumers every year, like the Greater Copenhagen DH system does. What these five types all have in common is that they supply heat to multiple consumers and that the company that owns and operates the distribution system is not the same organisation as one of the connected consumers. For example: a Danish cooperative DH company that operates its own gas-fired boiler, owns the distribution system and supplies heat to roughly 1,000 connected households is not owned by only *one* of its consumers, but by all consumers. Therefore, it is considered a DH system.

9.2.2. Technical design types

Now it is made clear what is considered a DH system and what is a 'regular' heating system, the second step will observe the variations in technical design and operation of the DH system itself. Besides physical dimensions of the DH system, there are more design factors that determine the technical properties and operational characteristics. Two important design factors are used in this step to classify systems according to their technical features:

1. **Heat source;** the type of the main heat source tells a lot about a DH system. Feed-in temperature, pressure, load profile, CO_2e-emissions and security of supply are all examples of characteristics that depend on the type of heat source. This regards both the production technology and the 'fuel' that is used. This distinction is important, as two sources can differ significantly even when they use the same fuel – for example natural gas – but different technologies – for example CHP and heat-only boiler.
2. **Temperature regime;** the temperature the hot water (or steam) in the transmission and distribution system has, is important for many different reasons, like the energy efficiency because of heat losses in distribution, minimal temperature level that is necessary to heat certain buildings or whether sources can reach the right temperature to feed-in to a system.

For each of these technical design factors a range of options is given in Table 12 below. This results in many different configurations; for a few of these configurations an example of a Dutch or Danish DH system is provided, showing the acronym for these (sub-) systems as used in sections 5.1.1 and 5.1.2, or the name of the city if these examples were not discussed in the case studies or have no abbreviation. The examples provided in Table 12 are also used in Table 13. These systems are not further elaborated upon and only function as an example.

There is a vast number of potential heat sources; many different heat sources are used in DH systems all over Europe already and this number can only become larger in the future, as – in principle – any source of thermal energy can be used in DH systems. In order to keep the *technical design framework* in Table 12 at least a very little bit reader-friendly, only a selection of frequently used and/or promosing heat sources are selected.

The temperature regime in a DH system actually consists of two factors: a forward temperature – from the heat source to the building – and a return temperature – from the building to the heat source. In this framework the forward temperature (FT) will be used to classify DH systems, as is common practice. There are four categories that are distinguished:

- High temperature (HT) systems with a forward temperature of over 70°C
- Medium temperature (MT) with FT between 40°C and 70°C
- Low temperature (LT) with FT between 20°C and 40°C
- Very low temperature (VLT) with FT lower than 20°C

The type of the main heat source in a DH system and the temperature regime of that system are correlated. High temperature heat sources, like CHP-plants or most heat-only boilers, often feed in to DH systems with a high forward temperature. Naturally, low temperature sources like solar thermal or surface water facilities feed in to LT or VLT systems. However, heat sources can also feed in to systems with a FT that is higher than their production temperature generally is, for example by boosting this temperature with the use of a heat pump just before feeding it in. This might not always be energy- or cost-efficient though. Lower temperature sources can also feed in their heat to a return pipe that has a lower temperature level than a forward pipe, for example when cascading techniques are used.

Still, when looking at DH systems like those in Greater Amsterdam and Greater Copenhagen, these can be categorised as high temperature systems and receive the majority of their heat supply from high temperature CHP-plants, like the natural gas-fired Diemen CHP-plant and AEB waste incinerator in Amsterdam, the biomass- and natural gas-fired CHP-plants in Greater Copenhagen or the heat-only boiler on biomass of SVP, in the city of Purmerend.

MAIN HEAT SOURCE		TEMPERATURE REGIME			
		Forward temperature level			
		VLT	LT	MT	HT
		FT < 20°C	*20°C < FT < 40°C*	*40°C < FT < 70°C*	*70°C < FT*
CHP	*Natural gas*				GC & AMS-SE
	Biomass				GC
	Waste incineration				GC & AMS-WPW
	Other				
Heat-only boiler	*Natural gas*				
	Biomass			Zaanstad	SVP
	Electricity				
	Other				
Other	*Geothermal*			Delft	
	Surplus heat		Roermond	Delft	
	Solar thermal				
	Surface water				
	Sewage water				
	ATES				

Table 12 – Technical design framework, showing the many different configurations of the possibilities for the two system design factors of "type of heat source" and "temperature regime". A few examples of DH systems are given in blue

Many of the heat sources that are considered renewable are LT heat sources. Higher temperature renewable sources do exist, but to a lesser extent. Examples are electric heat-only boilers, although only the renewable share of electricity in the mix is included as renewable, the 'renewable part' of waste incineration and biomass – which in many European countries is classified as renewable. Nevertheless, the majority of sustainable heat sources deliver a temperature lower than 70°C and could therefore be more easily connected to a MT, LT or even VLT DH system.

Lastly, the temperature regime is not only determined by the type of heat sources, but also by the characteristics of the building stock that is connected. In general, older buildings require a higher temperature than newer buildings, as the latter group is often better insulated and has an improved heat delivery system. In Greater Copenhagen neighbourhoods with a relatively high share of older and/or poorly insulated buildings require that the temperature level of the (distribution) system in that area is high enough to compensate the heat losses within the building. However, there also are numerous examples of buildings that are relatively new and could do with temperatures below 70°C, but are still connected to a HT system. The practice of connecting brand new buildings or even homes that are still to be built is an increasingly controversial subject (Van Hest, 2020).

9.2.3. Organisational design types

Now that the most 'tangible' aspects of a DH system – its dimensions, temperature level and heat source – have been discussed, the third and last step in the identification of DH system types will focus on the organisational design of DH systems. This organisational design might not always be the most visible and is not regarded as a fascinating subject by the average consumer. However, the organisational design of a DH system is a highly relevant feature of the DH system and can be very defining for the system's general functioning and the extent to which it answers to the interests of affected stakeholders. There are three factors included in the DH system's *organisational design framework*:

1. **Unbundling;** whether the roles of producer, TSO, DSO and provider are divided over different stakeholders or vertically integrated into one stakeholder can have a significant effect on the system's functioning. There are different degrees of unbundling of roles, as discussed in section 3.2.2; administrative, organisational, legal and ownership unbundling.

2. **Ownership;** although it normally should not have a direct effect on the system's operation, the ownership structure of the DH company might be of greater influence on the DH system's functioning than expected. Three main ownership types are distinguished; public ownership, cooperative ownership and private ownership. In cases of unbundling of roles in the DH system, the ownership of the transmission and distribution companies is most relevant and is intended in this step.
3. **Third-party access;** the extent to which a 'third' party – not being (one of) the incumbent DH company(-ies) in the system – is able to gain access to the system, either in the role of producer or the role of provider. A DH company might choose to not provide access to other parties, might be willing to negotiate about granting access, might be obliged to negotiate over access or might even be obliged to grant access when certain conditions are met. Which of the above four options is applicable to a DH system can have quite some influence on the system's functioning and is thus incorporates as a relevant factor in this organisational design framework.

THIRD-PARTY ACCESS		**GRID MANAGEMENT**					
		Vertically integrated			**Unbundled (partially)**		
		Public	*Cooperative*	*Private*	*Public*	*Cooperative*	*Private*
No TPA		SVP		AMS-SE			
Voluntarily negotiated	*Producers*				GC & AMS-WPW	GC	AMS-WPW
	Providers						
	Both				Zaanstad, Roermond, Delft		
Obligatorily negotiated	*Producers*						
	Providers						
	Both						
Regulated	*Producers*						
	Providers						
	Both				Dutch electricity system		

Table 13 – Organisational design framework, showing the many possible configurations of the system design factors of "unbundling", "ownership" and "third-party access". A few examples of DH systems are given in blue

Although there are, according to theory, several possible ways to organise third-party access, in the DH practice there are mainly two options that are seen: either no TPA or voluntarily negotiated TPA and in almost all cases this only regards TPA for producers, as can be seen in Table 13. There are no known examples of DH systems with (ex-ante) regulated TPA, like there is in the Dutch electricity sector. Examples of obligatory negotiation on TPA are very limited too and experiences in Sweden showed obligatory negotiated TPA did not reach the intended effects of strenghtening the position of consumers and achieving a more effective DH market with lower prices and environmental improvements. The conclusion of the Swedish government study was to impose regulated TPA and, when competition would arise, enforce legal unbundling of integrated DH companies (Government of Sweden, 2011, p. 22). Nevertheless, this proposal was not implemented.

Within the options of no TPA and voluntarily negotiated TPA there are some variations. Some DH systems have no TPA, but the DH company has never explicitly stated this would not be possible. Other DH systems with voluntarily negotiated TPA have third-parties feeding in in some way, but might in fact be very reluctant to grant access to others. By contrast, there also are DH systems where the possibility to gain access to the system is actively promoted, like in the large Stockholm DH system (Stockholm Exergi, 2019) or in the city of Zaanstad in the GA area even for both producers and providers (Firan, 2020), but in principle that is still voluntarily negotiated access. Moreover, it can even be questioned what the (legal) difference is between no TPA and voluntarily negotiated TPA, as in both cases there is – besides possibly signed contracts – no legislation that prevents the DH company from granting access or not.

The factors of unbundling and TPA are more or less related. There are exceptions, but in general the extent to which a DH system is unbundled or vertically integrated influences the likeliness of access being granted. Vertically integrated DH companies seem to have a strong incentive to not provide access to other producers (or providers), in order to protect their heat sales and – thus – the business case of their production facility. As said, this does not have to be the case, but many sources, like the Swedish study mentioned above, point to a strong relationship between TPA and unbundling of roles in DH systems.

The last factor of ownership is not a factor that has a very direct influence on the DH system. There are no straight operational benefits or disadvantages and no direct economic improvements or downsides. However, more sophisticated differences might together have a significant impact. Differences are mainly in:

1. **Representation of consumers and other citizens;** the ownership structure of the DH company – and especially the grid operator/DSO – influences the way consumers are represented and to what extent their interests are promoted within the DH company's organisation. Cooperative ownership shows a very direct way of representation of consumers and stakeholders' interests and often improves societal support. To a lesser extent, the same effects can be seen in municipal ownership. Private ownership does not show these benefits in representation and support;
2. **Financing costs;** the costs of financing, like interest paid on loans, are generally higher for projects and investments with higher risks. Public institutions are often considered to be exposed to a lower (financing) risk than private organisations and can therefore take out loans on superior conditions, compared to private loans. In many European countries citizen cooperatives can also obtain favourable loan conditions, as they are often supported by governments that guarantee these loans.
3. **Efficiency;** there is often no directly identifiable reason, but private companies are frequently thought to be operating more efficiently, as they have a stronger (economical) incentive to increase efficiency to lower costs and raise profits, compared to public organisations. However, this is not necessarily the case and the effect might be much stronger in case of a competitive market than in a market with little to no competition, especially when only the transmission and/or distribution is considered.

9.3. Relationship between system design types and requirements

Identifying these system design types helps to understand the many ways a DH system can be designed and organised. To be able to also understand how a certain technical or organisational design affects the system's functioning, it is important to relate these design types to the system requirements that could be established and to the underlying stakeholder interests. This section will shed light on the relationships between the three steps of system design identification and the system requirements and stakeholder interests of chapter 6 and 7.

When looking at the system requirements of chapter 7, it is noticeable that they relate to a wide range of subjects and factors. Some of these requirements are associated with physical or technical elements, others concern regulatory matters or policy issues. It is therefore not a surprise that the factors that are incorporated in the design type frameworks of step 1, 2 and 3 of section 9.2 do not relate to all of the twenty-four potential system requirements that were described in section 7.1. After more close examination of these requirements, it is stated that system requirements mainly relate to one of the following groups:

- **System design factors;** these are the factors that are included in the framework of section 9.2;
- **Regulatory & policy framework factors;** these system requirements are not related to a specific DH system's design, but mainly to the factors that shape the legislative and policy framework that (national) governments establish;
- **Boundary conditions;** these system requirements relate to factors that are pursued and in many cases need to meet a minimum value in order for the system to be viable, logical or functional. An example would be that a minimum heat demand density is pursued in order to make the DH system economically viable.

For example, the requirement of having a low temperature DH system, which was linked to four different stakeholder interests in section 7.2, is a requirement that mainly relates to *system design factors*, like the ones incorporated in section 9.2. This requirement does not have much to do with *regulatory & policy framework factors*, like price regulation, obligatory connection or planning. In order to understand how DH system design types relate to system requirements and stakeholder interests, the connections of the system design factors that are used in the three steps of the previous section with the system requirements that relate to these have to be analysed.

The system design factors included in the first step – determining if a heating system is a DH system or 'regular' heating system – are practically unrelated to the system requirements. For example, the requirement of having *integration of roles in the DH system* is focused on the integration of the roles of producer, DSO and provider, not on whether a consumer also operates its own heating system, like is relevant for step 1. Therefore, the relationships of the first step are not considered very relevant, as it does not really concern a DH system's design, but mainly whether or not it is a DH system in the first place. These factors are thus not further examined.

The system design factors of the second step, regarding the system's technical design, are related to a number of requirements. Looking at the design factors of the *temperature regime* and *type of heat source* in Figure 45 and Figure 47, it is clear several requirements can be linked to a DH system's technical design. Note that these links do not specify a positive or a negative relationship between the system design factor and the requirement. They simply indicate a requirement can demand something from the technical design of a DH system and, vice versa, that to what extent a certain technical design element satisfies a requirement impacts the stakeholder interests that are affected by this requirement.

The temperature regime of a DH system has an influence on a number of requirements, as is shown in Figure 45. Whether the forward temperature within the system is high enough determines if a comfortable indoor climate can be realised. On the other hand, a forward temperature that is too high might have a negative effect on the overall sustainability performance of the system, due to greater heat losses in transmission and distribution. This shows the opposite effects a certain technical design choice can have on different requirements. The temperature regime is also related to the requirement of having a low temperature DH system, in order to improve sustainability and increase the potential for LT renewable sources. This might also lead to having multiple producers in the system, as LT sources often have a lower capacity and thus more are needed, although that mainly depends on factors included in step 3.

The type of heat source also has quite an impact on meeting various system requirements, as illustrated in Figure 47. The temperature regime and heat source type are generally interconnected. This appears from the influence a heat source has on meeting the requirement of having a forward temperature that is high enough; introducing a certain heat source in a DH system could lead to not meeting the required temperature level for achieving a comfortable indoor climate. On the other hand, some heat sources can form a barrier to realising a low temperature DH system; dependency on a gas-fired CHP-plant could obstruct lowering the system's temperature level. Wanting to integrate the DH system with the power network or taxation on non-sustainable heat production can both affect the (selection of a) type of heat source.

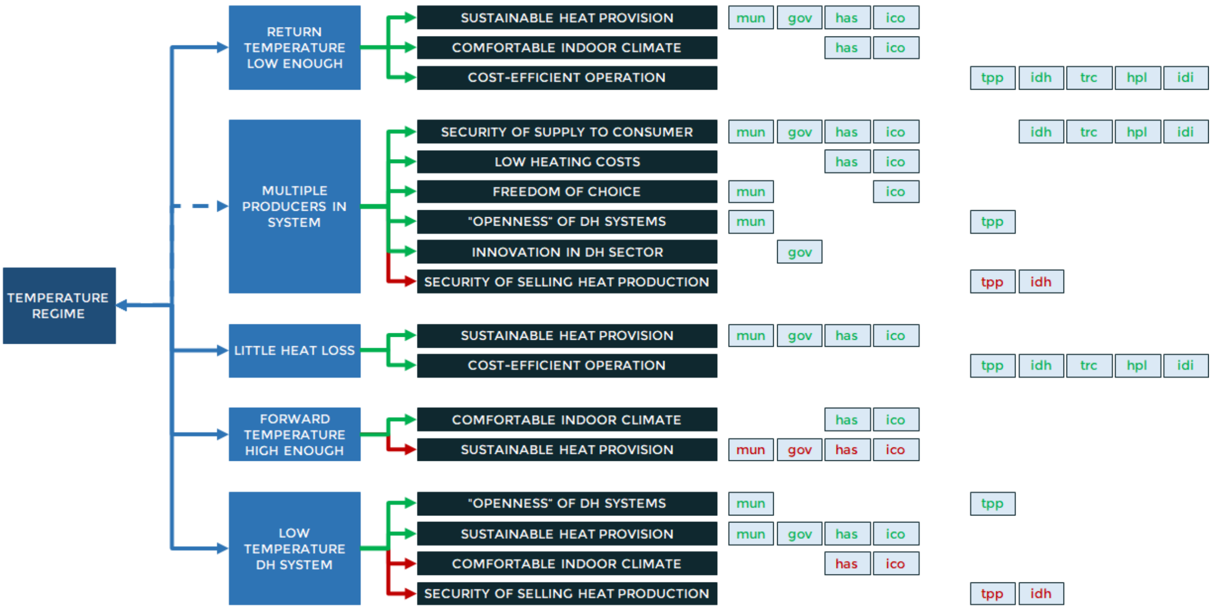


Figure 45 – Relationships between the system design factor of "temperature regime" and five requirements, each with the stakeholder interests they have an influence on and which stakeholders share these interests (own illustration)

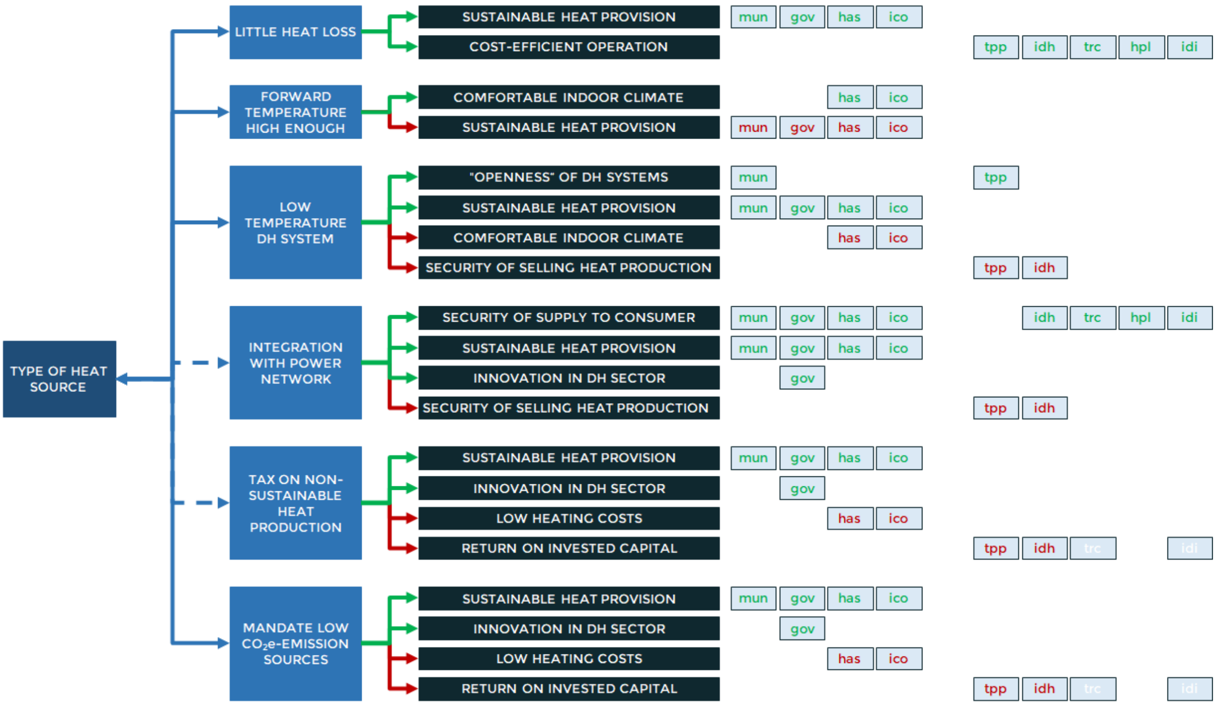


Figure 47 – Relationships between the system design factor of "type of heat source" and six requirements, each with the stakeholder interests they have an influence on and which stakeholders share these interests (own illustration)

Going to the third step and focusing on the requirements that are related to the organisational design of the DH system, it becomes more clear why the organisational design is considered quite significant to the system's functioning, as was stated in section 9.2. The (organisational) system design factor of *unbundling* can be considered to be related to five of the identified requirements. Logically, unbundling relates to the requirement of having an integrated DH company, as is shown in Figure 46. Vertical integration could have a positive impact on the security of the sale of a producer's heat and might have benefits regarding cost-efficiency in operation of the system. On the other hand, freedom of

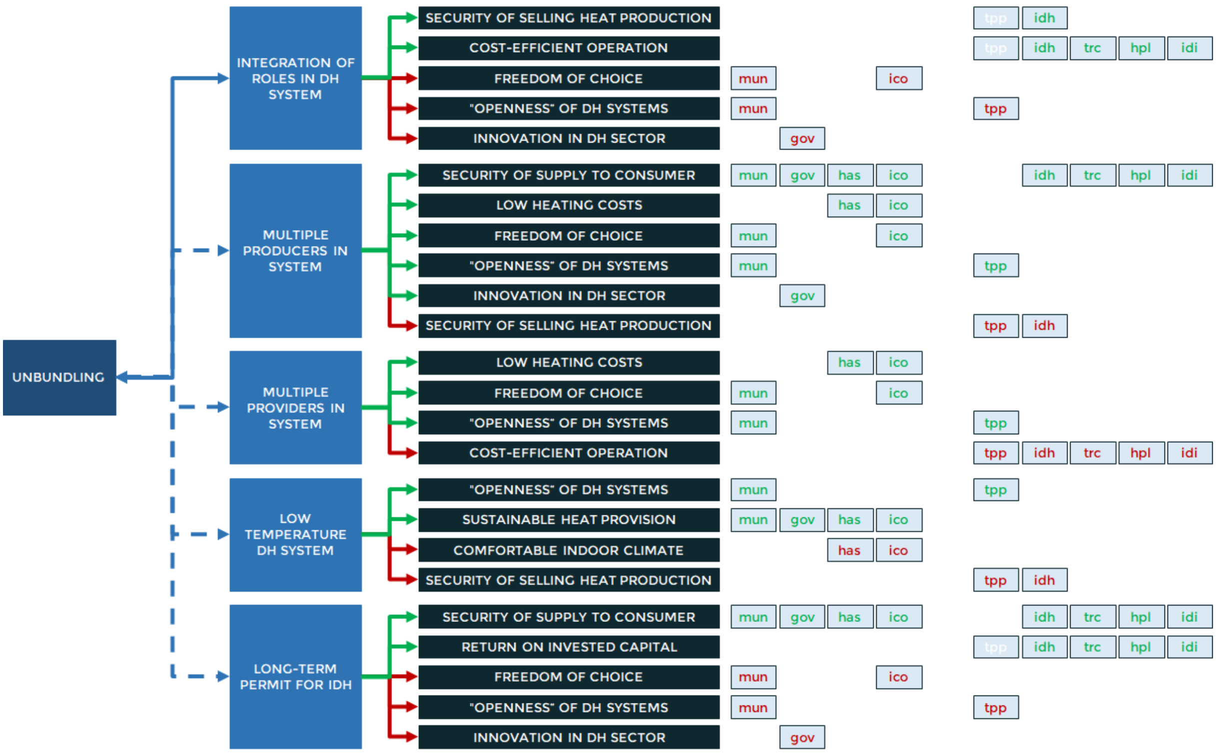


Figure 46 – Relationships between the system design factor of "unbundling" and five requirements, each with the stakeholder interests they have an influence on and which stakeholders share these interests (own illustration)

choice for consumers and the stimulation of innovation in the DH sector may be limited and the system is often less 'open' to third parties. This also explains the relationship with the requirements of having multiple producers and/or providers in the system, which are thought to have potentially favourable effects on e.g. the freedom of choice, heating costs, innovation and security of supply. Another, more loose relationship of unbundling exists with the requirement of having a low-temperature DH system, mainly because of the possibility to eliminate the incentive for an integrated DH company to adjust the system temperature to the optimal level for the company's own production facility, regardless of what is the societal optimum, for example with respect to the building stock or to sustainability.

The design factors of unbundling and third-party access show a relatively strong (cor-) relation to each other, as was explained in the previous section. This explains the factor of third-party access relates to a number of system requirements that we saw with unbundling, as can be seen in Figure 46 and Figure 48. For example the relationship with the requirements of having multiple producers and providers in the DH system, although the links to third-party access are more direct than to the design factor of unbundling. Creating better or stronger regulated access to third-parties may have a positive effect on these two requirements, which could influence the stakeholder interests of having low heat costs, freedom of choice and innovation in the DH sector, to name a few. Negative effects on the security of heat sales for (incumbent) producers or on the cost-efficiency of the system's operation are also possible.

Weaker links exist with the requirement of not having heat purchasing agreements with producers and the requirement of integrating roles in the DH system. The absence of purchasing agreements with heat producers could stimulate the viability of third-party producers' business cases, as competition for heat purchases is not obstructed by existing contracts. This could promote market entry, enhance innovation and create freedom of choice. On the other hand, it could also hamper operational efficiency, jeopardize the security of incumbent producers' heat sales, lower the return on invested capital for these parties and therefore threaten their business cases. Third-party access can roughly be considered to provide potential benefits to municipalities, national governments, consumers and housing associations, where it could mainly bother (existing) integrated DH companies.

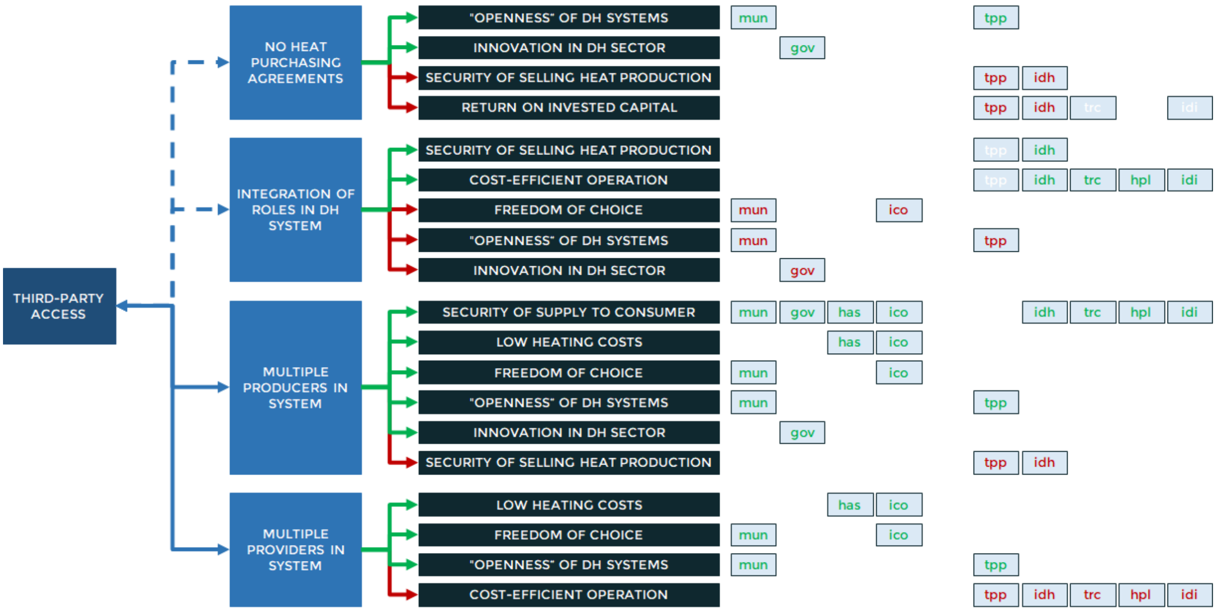


Figure 48 – Relationships between the system design factor of "third-party access" and four requirements, each with the stakeholder interests they have an influence on and which stakeholders share these interests (own illustration)

Lastly, the issue of ownership is discussed. More specifically, ownership of the DH grid is considered, whether it is in a (partially) unbundled form or integrated into one company with production and delivery. As is illustrated in Figure 49 ownership directly relates to only one system requirement, namely the requirement of including consumers in the design and operation of DH systems. Although the ownership structure of a DH company does not always directly influence the inclusion of consumers, it at least indirectly affects the position of consumers. In case of a cooperative DH company, consumers are indeed directly involved in design and operation of their DH systems, as they collectively are the owners of the system. With public ownership, like a municipally-owned DH company, consumers are not the direct owners but are, together with non-consuming citizens within their municipality, indirectly represented in the DH company itself. A municipal owner will, at least in theory, promote the interests of its citizens. This is not necessarily the same as direct inclusion or involvement of consumers in the planning process, but principles of good governance – like transparency and responsiveness – require the municipal DH company to do what is in its power to address their consumers' needs and to openly communicate about it.

Figure 49 – Relationship between the system design factor of "ownership" and one requirement, with the stakeholder interests it has an influence on and which stakeholders share these interests (own illustration)

Concluding, the technical design of a DH system and the design factors that are involved are considered to mainly be related to requirements that regard heat loss and efficiency, emission levels, integration with the other energy systems and the potential for third-party producers. On average lower temperatures are associated with higher potential for (LT) renewable sources and a diversification of both heat sources and (third-party) producers. Higher temperature and especially larger heat sources are thought to sometimes create lock-ins and dependency on these sources for baseload production could obstruct development and entry of new (LT) heat sources. Overall, shifting to lower temperatures is mainly considered to benefit municipalities (given their sustainability targets) and the consumers that value sustainability and whose building can handle a lower forward temperature.

The organisational design of a DH system and related design factors are mainly considered to relate to issues of competition, innovation, operational efficiency, a potential price reduction and consumer participation and representation. Unbundling of roles and introducing (a form of) third-party access are thought to mainly be beneficial to the so-called 'passive' stakeholders (as discussed in section 7.2) and to be a potential threat to incumbent 'active' stakeholders. The factor of ownership mainly influences consumer representation and the promotion of interests of 'passive' stakeholders.

9.4. Conclusion

Two different district heating systems are never identical. The design of a DH system is considered to be tailored specifically to its context, so they share similarities at most. However, as systems do regularly share some characteristics, their design can be categorised in certain system design types. In order to understand how the design of a DH system can contribute to the transition towards a sustainable heat provision for its stakeholders, it is also important to understand how these design types influence the interests of these stakeholders and how they relate to requirements that can be established in order to satisfy these interests.

This chapter provides an answer to the fourth sub-question.

SQ4	What are possible district heating system design types and how do these relate to stakeholder interests and system requirements?

First, the sixteen factors in DH system functioning, as discussed in section 3.2, are evaluated and identified as *system design factors*, *regulatory & policy factors* or *boundary conditions*. The system design factors are considered to be influencing the DH system's design and therefore its functioning. The regulatory & policy factors together determine the legislative framework that is established by a (national) government to regulate, organise and stimulate the country's DH sector. Boundary conditions are criteria on which a DH system's design needs to meet a certain minimum value, for example in order to be economically viable or technically possible.

Three of the system design factors are used in the first of three steps to determine if a heating system is a DH system or a 'regular' heating system. Two others are used to establish *technical design types* for DH system designs. The last three factors are incorporated into a framework that distinguishes *organisational design types*. The system design frameworks that are established to categorize DH systems are discussed in the second section.

The third and last section of this chapter assesses the relationships certain technical and organisational design types have with the requirements and stakeholder interests that were identified and discussed in sections 6.2 and 7.1. The technical design of a DH system is viewed to mainly be related to matters of technical efficiency and heat loss, the potential for third-party producers, CO_2e-emission levels and energy system integration. The organisational design is regarded to be related to matters of innovative capacity, competitive pressure, potential for decreasing prices, operational efficiency and consumer representation and participation.

10

IMPROVEMENTS FOR THE PLANNING FRAMEWORK

Stakeholder involvement, transparency & design differentiation

Ørsted's *H.C. Ørstedsværket* CHP-plant, Copenhagen

The planning process of a district heating system should be organised in such a way that it contributes to the realisation of system designs that satisfy the needs of all stakeholders and meet their interests. As DH is expected to play an important role in the transition to a renewable heating sector of many European countries, it is important the heat planning process in those countries is suited to support all stakeholders by including their interests. This chapter will elaborate on possible improvements that can be made in the planning process for DH systems in metropolitan areas, in order to be able to support stakeholders in the energy transition.

This chapter will answer the fifth sub-question.

SQ5	What improvements can be made in the planning process of district heating systems in metropolitan areas, to support stakeholders in their transition towards a sustainable heat provision?

In the search for possible improvements that can be made in the planning process, two aspects are considered: the planning process of DH systems and the national and regional policies and regulation regarding the DH sector. The first section of this chapter presents the challenges in the heat planning process in metropolitan areas and the improvements that can be made in order to tackle these challenges. The second section briefly elaborates on possible improvements for policy and regulation regarding the DH sector; both regulation regarding the planning process and regulation that considers DH systems after the planning process is ended and the system is designed, constructed and operated.

10.1. Improvements for the planning process

This first section aims to identify possible improvement for the heat planning process for DH systems, based on the challenges these processes face. Both the challenges and improvements will be focused on the planning process around DH systems in metropolitan areas and will consider the support for different stakeholders in the context of the heat transition in European countries. When discussing the 'DH system design process' this mainly concerns the process after heat planning, thus starting at the moment a set of system requirements is established and a company is assigned to design and subsequently construct a DH system, as described in section 8.1.

10.1.1. Challenges

As for probably every large and complex technical system, the planning process around DH systems faces challenges. Nonetheless, these challenges have to be identified and dealt with by constantly making improvements in these processes. First, challenges are identified.

Stakeholders in DH systems have very different interests and their influence on the system's design and operation varies significantly. The specific interests of stakeholders vary both in content and direction and in the number of stakeholders that share an interest. The interests and influence an individual stakeholder has do not always correspond and 'passive' stakeholders have a lower influence on the planning process than 'active' stakeholders. The stakeholder types that only connect to the system have the least influence, despite often being quite dependent on the system and particularly for individual consumers there is a major disbalance between interests and influence. Especially as individual consumers often form the largest group of stakeholders, this disbalance is considered a challenge when a DH system that satisfies all stakeholders and their interests is pursued.

When observing the heat planning processes themselves, it is noticed there is some involvement of stakeholders in the heat planning process, mainly through public consultation sessions. However, direct involvement of stakeholders – other than the DH company and to a lesser extent the municipality – in final stages of the planning process and subsequent design process of the DH system is very limited. This leads to the fact that the main form of 'passive' stakeholder involvement and representation is through cooperative or public ownership of a DH company, as this ensures a seat at the table, either more or less directly. Despite it being a valuable possibility, it might not be preferred to only be able to achieve involvement and representation through ownership. Public ownership can be a merely indirect way of involving stakeholders and representing their interests, cooperative ownership might not always enjoy sufficient societal support and thus be feasible and private ownership types might be excluded when citizen representation is valued highly. In the Greater Copenhagen (GC) DH system (passive) stakeholder involvement is primarily ensured through municipal and cooperative ownership of DH companies, in the Greater Amsterdam (GA) area this involvement is considered much lower, mainly because the majority of the DH system is in private ownership.

Another important challenge is the fact that many DH systems are not able to properly adapt to changing circumstances in the light of the energy transition. Also, given the way the planning process is currently organised, it appears these are incapable of improving that ability in new systems. When looking at the GC and GA DH systems the ability to adapt seems quite limited. This limited ability is because of both physical or technical barriers – like the strong dependency on large-scale CHP- and waste plants and the lock-in situation this creates – and organisational barriers – like the integration of roles, mainly in the GA area, that creates incentives to protect existing assets and thus hinders adaptation.

Zooming in on the technical design and organisation design of a DH system, as is described in section 9.2, it is observable that a certain design type might benefit some stakeholders more than others. For example: a DH system with a particular technical design that includes a low forward temperature and LT renewable heat sources might benefit municipalities and (a part of) individual consumers more than a privately owned integrated DH company. Or a DH system with an organisational design that involves unbundling of roles and third-party access for producers might be more beneficial to 'passive' stakeholders than to (incumbent) 'active' stakeholders. However, even though these design types could be preferred by the majority of stakeholders in a certain area, when these stakeholders have a lower influence on the planning process or there simply are few options due to a lack of competition and resulting monopoly power, these design types might not be implemented. Stakeholder involvement and/or representation is therefore considered very important for achieving a DH system design that satisfies all stakeholders.

10.1.2. Improvements

Given the considerable challenges in the planning process, improvements are essential to establish appropriate and future-proof DH systems. The improvements that are suggested in this section will respond to the challenges discussed above. They will be mainly focused on stakeholder involvement in the planning process and connecting stakeholder interests and requirements to system design factors and types.

Stakeholder involvement – other than the municipality and DH company – is already limited and currently seems to already stop before the conclusion of the heat planning process. When a DH system is selected as the appropriate heating technology for a given area, especially the 'passive' stakeholders are not included in determining the system's physical features, technical and organisational design and the formation of the system. The system's design will be based on a set of system requirements that together form the product or system requirements document that is used in a tendering procedure. The criteria that are used to evaluate the received bids are essential in achieving an adequate system design. However, both these system requirements and evaluation criteria often seem to not be properly discussed with all stakeholders and corresponding to their interests. The main suggestions for improving the planning process are discussed below.

Proportionally including all stakeholder types in establishing system requirements

By actively including all stakeholders in the establishment of system requirements, every stakeholder has the opportunity to promote its interests and, together with the other stakeholders, pursue the system requirements that best suits the needs of the collective. This involvement could be organised in different ways, like exploratory sessions where (representations of) stakeholders can express their interests and concerns, or in stakeholder type-specific sessions where each stakeholder type discusses the system requirements it would like to see incorporated. The degree of influence a certain stakeholder can exercise on the process of establishing system requirements should however represent the level of that stakeholder's interests; not resulting in too little influence, but also not in too much influence for a certain stakeholder. Both the technical and organisational design of the DH system should be fitted to the system requirements that are established in this process. Municipalities are already responsible for heat planning and implementation and, as a result, are the appropriate party to coordinate the process of stakeholder involvement in establishing system requirements. However, they often currently face a lack of knowledge and resources and should therefore be supported in their responsibilities.

Transparent tendering with clear and broadly supported evaluation criteria

The evaluation criteria for the incoming bids also need to be in correspondence with stakeholder needs, provided this still satisfies procurement legislation. The tendering procedure should be transparent to the public and contain clear evaluation criteria that are published in advance. Within the process of establishing system requirements and evaluation criteria, the adaptability of the DH system's design should be considered and incorporated.

Allowing different organisational and technical system designs

As procurement with only one or very few bidders is not considered very beneficial to the final outcome, it should be at least made possible and preferably stimulated that more parties are willing to respond to an invitation for tenders. This could be achieved by actively stimulating innovation through subsidies and loans, but also by organising the procurement procedure in such a way preparing a bid is a realistic option for more different organisations. The planning process and subsequent procurement procedure should therefore leave room for different organisational designs, as more parties will then become eligible. Having different options, both in organisational and technical design types, is also recommendable as a DH system's design should be adjusted to the area's specific context.

Involving 'passive' stakeholders in planning to stimulate citizen support and initiative

Lastly, involvement of 'passive' stakeholders and especially of (prospective) consumers in the planning process might not only help promoting their interests, but could perhaps also stimulate citizen initiatives and citizen participation in DH or even stimulate the founding of consumer cooperatives. Societal support probably benefits from this.

10.2. Improvements for regulation & policy

Based on the research that is conducted and discussed in previous chapters, improvements can also be suggested for regulation and policy regarding the DH sector. Some of these improvements relate to regulation of the planning process, other improvements relate to DH systems that already passed the planning process and are being designed or already operational. To give an example: improvements can consider regulation and policy related to involvement of stakeholders in the establishment of system requirements, which would be an example of regulation that is 'flanking' or supporting the planning process. Other improvements might for example consider transparency of tariffs, which is an example of regulation that does not have much to do with the planning process, but with regulation of systems that are operational. This section will very briefly discuss improvements in both of these categories.

Regulation supporting the planning process

Improvements that are suggested for the planning process need to be supported by 'flanking' regulation and policy. The regulatory and policy framework regarding DH is different for every country. Still, some aspects of the regulatory framework can be considered generally applicable.

First, regulation and policy should – amongst other things – facilitate an adequate planning process. Improvements for the planning process that are suggested and discussed in section 10.1.2 should therefore be supported by improvements of the regulatory and policy framework, if necessary. One important enhancement would be to require – by law – that municipalities establish guidelines within local policy that facilitate the involvement of all affected stakeholders in establishing system requirements. These policies should also stipulate how this involvement is executed. Moreover, this should be an integral part of heat planning, also connecting to the earlier steps of the planning process and fitted to the specific structure of the planning process in the country in question. When looking at Figure 43 and Figure 44, it seems this could be relatively easily implemented in both Denmark and the Netherlands. For example; in the Netherlands, all municipalities are required to have established a "Heat Transition Vision" (Dutch: *"Transitievisie Warmte"*) before the end of 2021, after which implementation plans have to be drafted for each neighbourhood, district or area. It would be recommended to incorporate the need for involvement of all stakeholders in establishing system requirements for each of these districts – or "heat plots" – before a DH company is selected and issued a permit.

Another improvement can come from allowing different system designs to exist, both on the technical design level and on the organisational design level. This is considered important for several reasons:

1. Stakeholder interests and requirements are considered specific and depending on the local context. By not allowing different kinds of technical and organisational design types, the DH system design cannot be customised for those particular needs;
2. Different areas have different local characteristics, like the quality of the building stock, availability of heat sources and other environmental features. These areas require a system design – both technical and organisational – that is tailored to their characteristics;
3. Varying system designs could attract more and different organisations that might be interested in participating in the DH system. This could increase competition for tenders and stimulate innovation.

Regulation or legislation that prohibits certain technical and/or organisational designs or puts restrictions on system design factors is therefore considered harmful to a properly functioning DH sector. This is especially very important to consider for policymakers of the national government of the Netherlands, as the Dutch Heat Supply Act (Warmtewet) is being renewed and heavily restructured. The current draft version of this Warmtewet does in fact put restrictions on – mainly organisational – system design types.

Regulation of operational DH systems

Besides regulation that concerns the heat planning process, the DH sector could also benefit from improvement of regulation and policies that concern DH systems when they already passed the end of the planning process. For example; the (*regulatory & policy framework factor*, see Table 9) factor of *transparency* can be considered important, given the many requirements and interests that relate to this factor.

For example: the requirement of *transparency of DH tariffs* (see Figure 50) is considered beneficial to interests of all five 'passive' stakeholder types and is related to the factors of *price regulation* and – thus – *transparency*. An improvement – at least for the Dutch DH sector – could be to increase the transparency of these tariffs, as this showed to be one of the main drivers of societal support and consumer satisfaction in Denmark (Galindo Fernández, Roger-Lacan, Gährs, & Aumaitre, 2016, p. 25). Another improvement, also based on Danish experiences, and related to the requirement of Figure 50 and of *benchmarking DH systems* (see Appendix G) could be to benchmark (comparable) DH systems against each other on matters like costs. This showed to increase efficiency and to also stimulate societal confidence and support (McDonald, 2019).

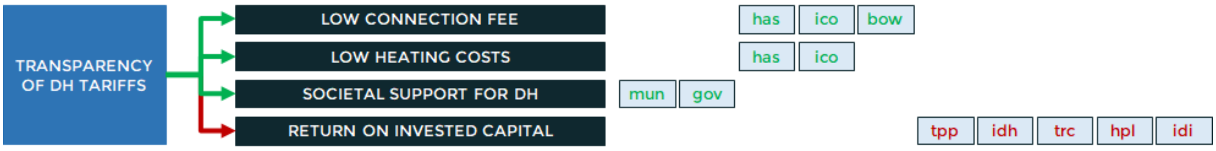


Figure 50 – The requirement of transparency of DH tariffs, the stakeholder interests that are connected and the stakeholders that share these interests (own illustration)

Depending on the influence of stakeholder types, the requirement of Figure 50 will or will not be incorporated in national DH regulation. Another improvement could be to, like is suggested for the planning process, also involve (representatives of) affected stakeholder types in the establishing of requirements for DH sector regulation, perhaps using the same kind of procedure as for system requirements in a specific case, but then on a national level. This could result in different regulation than without involvement of (all) stakeholders, for example in regulation regarding the factors of *transparency*, *obligatory connection* or *price regulation*, as these are factors on which the interests of the groups of 'active' and 'passive' stakeholder types often do not match. However, this is not part of the scope of this chapter nor this research in general and will therefore only be suggested, not further elaborated upon.

10.3. Conclusion

In order to design DH systems that benefit and represent all affected stakeholders in the transition of their heat supply, the planning process and supporting regulatory framework need to be suited to achieve this goal. Where either the planning process or the regulatory and policy framework do not do this, improvements are needed. This chapter studies what challenges exist and what improvements are needed. In doing so, the chapter provides answers to the fifth sub-question:

SQ5	What improvements can be made in the planning process of district heating systems in metropolitan areas, to support stakeholders in their transition towards a sustainable heat provision?

Challenges in the planning process can mainly be detected in lacking stakeholder involvement – especially of the 'passive' stakeholder types – and representation, disbalance in interests and influence of certain stakeholder types, low adaptability to changing circumstances in the energy transition and the fact that some promising system design types could be obstructed by an influential minority of stakeholders with interests that might oppose the interests of the (passive) majority.

A major improvement of the planning process can be found in actively including all stakeholders in the establishment of system requirements. This involvement could be organised in different ways and the level of influence should represent the level of a certain stakeholder's interests. Municipalities are – in most cases – the appropriate party to coordinate this process. Not only the system requirements, but also the evaluation criteria for the procurement procedure should reflect the interests of all stakeholders. An important requirement and/or evaluation criterion that should be considered is the adaptability of the DH system to future changes. The tendering procedure itself should be transparent to the public and leave room for different technical and organisational designs, as more parties might become eligible and willing to prepare a bid. Stakeholder involvement and having different design options could perhaps also stimulate societal support and citizen participation.

Improvements can also be made in the regulatory and policy framework, mainly in order to support the improvement of the planning process. Requiring municipalities to introduce or change policies that ensure all stakeholders are involved in establishing system requirements could strongly support the planning process. Changing or removing legislation that prohibits certain technical or organisational designs is recommended. Lastly, stakeholders could also be involved in formulating requirements for other specific DH sector regulation, as this could result in different regulation than without involvement of (all) stakeholders, for example regarding transparency of DH tariffs or other pricing issues, like benchmarking of comparable systems on their cost efficiency.

DISCUSSION

Implications and limitations of the research and its results

ARC's *Amager Bakke* waste incineration plant, Copenhagen

This chapter includes a discussion of the implications and limitations of this research, based on the findings as presented in the previous chapters. The first section contains the discussion of implications for science and knowledge building; what is the contribution of this research to academics? Then the implications for policy and legislation are discussed, valuable for policymakers and governments. The third section discusses the implications of this study for society and all of its actors, ranging from citizens – both DH-consumers and others – to housing associations and companies. Lastly, the limitations of this research are discussed, focusing on the limitations of the research methodology, of the collected data and of the conclusions and the generalisation of the results.

Scientific implications

There are several ways this research contributes to current scientific literature. This section will discuss the implications for academia of this study by reviewing these contributions, captured in four parts: the *definition of roles and factors*, the *description of the main stakeholders, their interests and influence*, the *identification of challenges in the planning process* and the *establishment of a descriptive framework for DH system design types*.

Definition of roles and factors in district heating systems

When reviewing existing literature, it quickly becomes clear there is no clear overview and no thorough, objective description of the different roles that can exist within DH systems. Many authors consider only a few of the roles that need to be fulfilled within the system, they automatically assume a certain role distribution among and/or integration within stakeholders, or they seem to confuse roles with stakeholders, or vice versa. Moreover, current academic literature often uses definitions that overlap and cause confusion about the activities and responsibilities of roles and the stakeholders that fulfil them (Hoogervorst, 2017, p. 28).

By clearly defining the roles that are fulfilled in every DH system – whether or not these are divided over different stakeholders – and doing this in such a way this definition is collectively exhaustive and mutually exclusive, this research adds to existing literature. It also clearly establishes the difference between 'roles' and 'stakeholders' and describe how they relate. Furthermore, the role definitions pave the way for objective and out-of-the-box thinking and reasoning about how DH systems can be organised and in what way these roles can or should be distributed among stakeholders.

In addition, the literature review also resulted in the identification and definition of fifteen of the most important factors of DH system functioning. Many, if not all of these factors have earlier been discussed in existing literature. However, there is no complete and clear overview of all factors that influence DH system functioning. Most research articles consider only one or a handful of factors and specifically focus on the impact of these on the DH system's operation. This study not only defines many important factors, but also considers all of these fifteen as (potentially) relevant to the system technical and organisational design and the resulting functioning of the system. Practical experience and expert opinions from the interviews support the findings from the literature review.

Factors like the *temperature regime* or the *type of heat source* are relatively well-known and visible. Still, even these are ill-defined, allowing for confusing about their boundaries, variations and implications for design choices. Moreover, other factors, like *role distribution* or *consumer representation*, are less obvious and less regularly discussed, even though they can be of vital importance to the DH system. By establishing one clear overview of all of these factors together, divided in four categories, this study contributes to the understanding of the fact that DH systems are large, complex and multi-faceted. It also shows factors can influence each other – like the relationship between *ownership types* and *consumer representation* – and combinations of factors can have a different impact from just the individual factors by themselves – like the combination of either *no TPA* or *regulated TPA* with either *public* or *private grid ownership*. Discussing these combinations and relationships already proved useful during stakeholder and expert interviews. Furthermore, using these factors to establish an initial descriptive framework for DH system design types – both technical and organisational – showed the possibilities of considering multiple factors together, even though they might not seem related first. By establishing a clear definition and coherent overview of fifteen of the most important factors, this research contributes to further discussion of interrelations between factors and their impact on system design and functioning.

Description of main stakeholders, their interests and influence

As stated above, roles in DH systems should not be confused with stakeholders within those systems. The six main roles should always be fulfilled within DH, the ten identified stakeholder types do not need to all be present. Based on a significant number of interviews in both Denmark and the Netherlands and with both stakeholders and experts, this research identifies and describes the ten most important stakeholder types in metropolitan DH systems in Europe. In doing this, it makes good use of the role definitions that are established earlier. In addition, it not only describes these stakeholder types and portrays their main characteristics – like roles, activities and possible ownership structure – but also identifies different interests that stakeholder types can have. Moreover, it combines both the content of these interests and the degree of interest in the system, with the influence that stakeholder type can exert on the system's design and operation.

Existing literature does not recognize all stakeholder types and tends to make assumptions about their interests. The scientific literature does also often not consider the ratio between the degree of interest and the amount of influence of a stakeholder. A major contribution of this research is in the fact that is does exactly this and shows there seems to be a strong disbalance between interests in and influence on DH systems among different stakeholder types. Using a power-interest grid, it demonstrates this disbalance is not only present, it is also concentrated towards the five 'passive' stakeholder types, in contrast with the five 'active' stakeholder types. These 'active' five are almost never all five present within a system, where the 'passive' five in fact often are, which enlarges this disbalance even more. This finding forms the basis of one of the main challenges that are identified in this research.

Identification of challenges in the planning process

In addition, stakeholder interests are coupled to system requirements and the factors these requirements relate to. By doing this, the study contributes to understanding the impact of the (dis-) balance of interest and influence, because drafting a system requirements set as the final step of the heat planning process determines the ultimate technical and organisational DH system design. Current literature does not deal with this issue, when it actually should in order to provide policymakers and legislators with the necessary knowledge to review the heat planning process, adjust it to represent all stakeholder interests and support them in the transition towards sustainable heating. This lack of proportional inclusion and appropriate prioritisation of all stakeholders' interests is one of the two main challenges that are identified in this research.

The second challenge that is identified is related to the adaptability of the DH system's design. Many authors of articles and research papers discuss developments and innovation in the DH sector and refer to 3rd, 4th and even 5th generation DH systems. However, the adaptability of the systems that are currently being built and have been built over the last decades is not discussed regularly and far from always taken into account. A lack of attention and/or awareness for this challenge could result in high costs for adaptation or technological or financial lock-in situations, as can already be seen in various countries and systems. By identifying these important but often overlooked challenges, this research adds to the existing body of knowledge and contributes by providing two new topics for future research on DH.

Establishment of descriptive framework for DH system design types

District heating systems come in countless variations and shapes, even though many of them are or at least look rather similar. In fact, not only do DH systems vary a lot, there also are other distributed heating systems – circulating hot water or steam to different buildings – that should not be considered a DH system. Still, these many different systems, being a DH system or not, are often all put together within the single expression of district heating system, that occasionally functions as an umbrella term and leads to confusion. This research contributes to scientific literature to clarify three things:

- What is considered a DH system and what is not
- What technical design types can be distinguished and based on which factors
- What organisational design types can be distinguished and based on which factors

By drafting this stepwise approach to distinguishing 'regular' heating systems from DH systems and describing a DH system's design, this study not only supports in having an objective and clear discussion about DH system design, but it also supports the planning process and subsequent decision-making in procurement and design, by illustrating the relationships between stakeholder interests, system requirements and – via the (system design) factors these requirements relate to – system design types. This descriptive framework is not intended to be used to "pick a design of one's liking and simply implement", but to shed light on these relationships and the fact the planning process should take this into account. It can assist in describing and comparing DH systems and in illustrating relationships and dependencies of system designs, system requirements and stakeholder interests, in order to support the planning process by doing so.

Policy implications

Besides adding to science, this research also contributes to policymaking and legislation. This section will discuss these contributions and the implications for policy on DH. First, the implications for the planning process are addressed. Then, the implications for legislation for and regulation of the DH sector are discussed.

Planning process

Even the mere description and illustration of the heat planning process could already contribute to the understanding of policymaking for the DH sector, as these planning processes run for months or even years, consist of many different steps and tend to have fuzzy boundaries. Besides simply adding to the understanding of these processes, this research also identifies several challenges for the heat planning process and makes some suggestions for improvements of this process. Policymakers and legislators in Denmark and the Netherlands – both on the national and local level – could turn these identified challenges and suggested improvements to their advantage by reviewing their heat planning process and implementing changes to better respond to these problems.

A major challenge for the current planning processes in both Denmark and the Netherlands lies with the fact that the ability of DH systems to adapt to changing needs, technologies and other circumstances is not embedded in the planning and subsequent procurement process. This opens systems up to the risk they later cannot easily change their technical or organisational design in order to adapt, creating lock-in situations and possibly high (societal) costs to escape from these circumstances.

Probably the most significant implication of this research – regarding policy for the planning process – is in the finding that the so-called 'passive' stakeholder types show a disbalance between their degree of interest in the DH system and their influence on the planning process and the system design that follows from it. The 'active' stakeholder types are considered more influential and having interests that are often opposite to the interests of passive stakeholder types, creating a situation in which the DH system design might not properly respond to the interests and needs of large numbers of stakeholders. The current planning processes, especially in the Netherlands, prove to be unsuccessful in proportional involvement of all stakeholders and therefore to be unsuited to facilitate the transition towards a sustainable heat provision over the coming years. This is an even bigger problem given the increasingly ambitious targets national and local governments set in the light of the 2015 Paris Agreement and their national climate goals.

These findings demonstrate the necessity of reviewing and revising planning processes, especially regarding the establishment of system requirements, as these are the key in translating (all) stakeholder interests to a suitable system design for each specific area, able to meet the needs of its stakeholders. Policymakers that are up for this task should not only consider the inclusion of all stakeholder types in establishing these requirements, but should also work towards increased transparency of the planning and consecutive procurement processes. The procurement procedure should not only be transparent and reproducible, but also incorporate clear and public evaluation criteria, also regarding adaptability of systems. To be able to realise this and to increase competition through transparent and open tendering, policymakers should establish guidelines for decent procurement that is based on visible and broadly supported system requirements.

Legislation and regulation

Even though the heat planning process is a major focus point of this research, it is not only the planning process that is considered. The research also considers the various aspects of regulatory framework and identifies challenges for and improvements of these rules and regulations. These policy improvements either relate to regulation that is supporting the planning process or to policy and legislation that regards the (economic or technical) operation of a DH system, like tariff regulation.

The necessity of involving all stakeholder types in the planning process, as discussed in the previous section, leads to the fact that this should be incorporated in supporting policy and regulation. This brings the responsibility for policymakers to include guidelines for stakeholder involvement. An implication for policymakers on the level of the national government would be to require local authorities – especially municipalities – to establish guidelines for stakeholder involvement and to implement these in local policies, stipulating how this stakeholder involvement is implemented and executed in the planning process. Requiring local authorities to do this, implicates that national legislation should be changed in order to facilitate this. Both in the Netherlands and Denmark legislators should take this into account and especially in the Netherlands, the current revision and reform of the Dutch Heat Supply Act or *Warmtewet* provides an outstanding opportunity to do exactly this.

Another potential improvement for legislation that is found to be promising – in general, not only in Denmark or the Netherlands – is to allow for various system designs to exist and to accept different configurations of system design factors, based on the system requirements that are set in planning. This would implicate legislation should not only allow these variations – thus by not regulating too much – but policy and regulation could also stimulate different system designs to be explored and competition and innovation to arise from this. Rigidly focusing on one or few (technical and organisational) system designs is thought to be blocking DH systems to be fit to the local characteristics, and the needs of specific stakeholders. Legislation should thus not be (too) restrictive when it comes to local system design variation, as this would be harmful to the potential benefits of DH systems in the transition to sustainable heating. Again, this is especially important for Dutch policymakers, as the draft version of their Warmtewet seems to be restrictive when it comes to the organisational design of DH systems.

A last implication of this research for policymakers and legislators can be found in the possibility to increase transparency in several aspects of the DH sector. Greater transparency could be pursued in tendering for new DH systems, in the structure of DH tariffs and in benchmarking between systems with similar characteristics. Between the two, increasing transparency is mainly relevant for the Netherlands, as Denmark already has rules and policies in place that safeguard a certain level of transparency on these three aspects.

Societal implications

By definition, district heating systems are systems located within dense urban areas, in the middle of society and with a wide range of stakeholders. It therefore may not come as a surprise that the findings of this research also have implications for society as a whole and for local DH communities in particular. This section will discuss the three most important societal implications of this research.

Stakeholder involvement and citizen participation

As discussed in the two previous sections, stakeholder involvement in the heat planning process is often limited, especially for certain 'passive' stakeholder types. The implications this research has for policy and regulation regarding the planning process and the involvement of stakeholders in drafting system requirements are also relevant on the societal level. Stronger involvement of passive stakeholder types can be considered to have a positive influence on meeting the needs of these stakeholders through the DH system design. This research not only identifies several challenges regarding this involvement, but also contributes by suggesting some improvements in order to tackle these challenges. If these improvements are considered and possibly executed, this might lead to stronger involvement of stakeholders. Moreover, especially the passive stakeholder type of the individual consumer will be helped by this and could engage in stronger citizen participation, for example through citizen initiatives and consumer cooperatives.

Awareness of possibilities and potential of DH

Many people, especially when working outside of the DH sector, seem to have a relatively simple and narrow view when it comes to DH systems and their design. This research shows the wide variation in technical and organisational system design types, each with a different influence on stakeholder interests and requirements. The research therefore contributes to raising awareness of the possibilities in system design configuration and of the large potential to include renewable heat sources, to work towards lower temperatures or to integrate decentral production, to name a few of the described trends. Especially for the group of passive stakeholder types – ranging from municipal and national governments to individual consumers, housing associations and building owners – increased awareness of the possibilities and potential could also foster participation and the urge to be involved. There is not "one district heating system", a DH system offers a range of options and possibilities that should be tailored to local characteristics.

Societal support

Perhaps the most important societal implication of this research for the development of the DH sector regards the societal support. This research shows several reasons for the difference in societal support for DH between Denmark and the Netherlands. To name a few: low stakeholder involvement, an unfit price regulation, a lack of transparency of DH tariffs and little municipal and cooperative ownership are all possible reasons for the lower societal support for DH in the Netherlands, compared to Denmark. On one hand, an implication of this research is that it shows multiple possibilities to increase societal support for DH, for example by dealing with the potential causes of societal resistance that are mentioned above. On the other hand, another implication is that national and municipal governments may feel resentful of themselves, as they hold the key to increasing societal support, as they are the appropriate parties to handle these problems and adjust policy and regulation. With this report in hand, governments can now deal with this and thereby increase and maintain societal support.

Limitations of the research

This section discusses the limitations of the research that need to be taken into account. These limitations regard three aspects of the research: the limitations of the research methodology, of the data that is gathered and of the results that are derived from this.

Limitations of research methodology

Even though the research methodology was carefully designed before the research was conducted and adjusted to gained insights a few times, the methodology could still be considered to show some limitations. First, the research started with a thorough literature review, focusing on roles and factors. However, especially the identified factors were based on an initial scan and consecutive snowball sampling of subjects and potential factors. As this method builds more or less on what the researcher 'stumbles upon' and is referred to by other literature, the set of factors that is identified may very well not be exhaustive and thus cannot claim to form a complete overview of all relevant factors to DH system functioning. This does not to the same extent concern the description of roles in chapter 3, as they are based on a more clearly demarcated value chain.

Also, the external validity of the chosen methodology is threatened due to the fact that it is a case study-based research, but only covers two cases and – even though 23 is a significant number – a limited amount of interviews (Verschuren & Doorewaard, 2010). However, strategic sampling, especially of the stakeholder interview candidates, resulted in a variety of different stakeholder types, in order to incorporate as many views and experiences regarding heat planning and system designs as possible. To ensure some degree of comparability and completeness of both cases, the selection of interviewees in both countries was aligned to include similar stakeholders and experts in both Denmark and the Netherlands. Also, the views of independent experts were included on matters like system design definition and influencing factors, in order to cross-check statements and arguments. Still, the relatively low number of interviewees and small number of cases limits the research.

The internal validity of the case studies, as part of the research methodology, was attempted to be improved by triangulation of sources, like Yin describes (2003). The researches makes use of both project documentation and stakeholder and expert interviews, supplemented by literature validation using the earlier findings from the literature review. However, fully verifying all findings was not always possible, as the semi-structured interviews did not always leave room for handling all relevant aspects. Therefore, properly validating all findings was not always possible, as goes for the results of the (cross-case) analysis that followed. The integrity of the data gathering process was safeguarded partly through recording and literally transcribing all 23 interviews with stakeholders and experts in both countries.

Limitations of data

When looking at the data that is gathered and the subsequent processing and analysis of this data, there are a few limitations that need to be considered. Three limitations are briefly discussed below.

Researching large district heating systems in European metropolitan areas makes for a relatively clear scope, but also limits the number of systems that are available to be considered for case studies. Selecting the cases of Greater Copenhagen and Greater Amsterdam was manageable, but many options were not available. This puts a constraint on the degree to which the researcher can select the most appropriate cases for answering the research question.

A second limitation regards the comparability of the two cases. Even though the selection of these cases and the comparability is carefully considered in section 4.1, there still are several characteristics of the metropolitan areas of Copenhagen and Amsterdam that show varying values, reducing the comparability and the degree to which lessons can be learned and practices can be transferred. For example the totally different energy situation of both countries in the 1960's, 1970's and 1980's – regarding the oil crisis in Denmark and the discovery of large natural gas reserves in the Netherlands – makes comparing the historical development and current situation more difficult.

Lastly, data is gathered mainly through literature review, case documentation, expert interviews and stakeholder interviews. These sources differ in terms of objectivity and validity of retrieved data. Where peer-reviewed papers are considered objective and valid, this is not always and to the same extent the case for case documentation and especially for stakeholder interviews. Especially the last source of stakeholder interviews can be considered both very valuable – given the large practical experience and unique insights – and very difficult – given the potential bias towards a stakeholder's own experiences and the incentive to sugar-coat results – at the same time. With both stakeholders and experts there is the risk an interviewee is pushing the limits of its own knowledge and experience and he or she might make unwanted assumptions or generalisations. Especially with experts, it is important to consider in what field they are experts, before accepting statements and interpreting parts of the interview. The partial dependency of the case studies on these interviews therefore exhibit limitations for the analysis of the data.

Limitations of results

The limitations that relate to the results of the analysis mainly consider the degree to which generalisation of these results and the findings is possible.

As the research only covers two cases in (north-western) Europe, the findings and conclusion of this study cannot automatically be generalised in order to make recommendations for or transfer practices to regions outside of this scope. For example: the findings of this research – like the lack of stakeholder involvement in heat planning – might already show limited potential for generalisation in itself, as every country has its own legislative and policy framework.

Generalising the findings in order to conclude or suggest anything on district heating systems in China or the United States is not recommended. Still, some elements of the implications, conclusions and recommendations could be generally applicable. Also, generalisation of the findings towards DH systems with different sizes, designs and contexts might be easier than towards other countries or other energy sectors.

Furthermore, the data, results of the analyses and findings based on these analyses face the risk of becoming outdated as for example the heat planning process in various countries can change. Especially with the (relatively) fast development in the Dutch DH sector, the results might be limited in their expiration date. However, the results will not as easily become fully obsolete, as changes and developments in the DH sector do not necessarily mean the findings, conclusions and recommendations are not relevant anymore. Again, looking at the Netherlands it becomes clear the Dutch Heat Act does not seem to be developing in a direction that makes this research worthless. On the contrary, the way towards this *Warmtewet* is moving could in fact lead to an even greater relevance of this research for Dutch DH companies, policymakers, consumers and other stakeholders.

CONCLUSION

Answering the research question and making recommendations

ARGO's *Energitårnet* waste incineration plant, Roskilde

This final chapter answers the main research question as the conclusion of this research. The answers to the research question and the five sub-questions are provided in the first section. The second section discusses several recommendations. The last section completes the research by making suggestions for future research.

Answering the research question

District heating systems are considered to have great potential to contribute to realising energy savings and integrating renewable sources into the heating sector. Especially in large and densely populated urban areas, district heating systems are thus thought to be able to improve the transition towards a sustainable heat provision for metropolitan areas. In order to do so, these systems should be able to support all stakeholders, as there are many parties affected directly or indirectly. However, it is not always clear how DH systems should be designed in order to realise their potential benefits and how the planning process will have to be structured to achieve the desired result. This study is therefore focused on the following research question:

RQ	How could the planning process and system design of district heating systems in metropolitan areas support stakeholders in their transition towards a sustainable heat provision?

Before being able to answer the main question, the problem is spread over five sub-questions that are each answered in the ten previous chapters. The answers to these sub-questions will be briefly discussed before answering the main research question, starting with sub-question 1 below.

SQ1	What are factors in the functioning of district heating systems and which roles can be distinguished in existing literature?

Within DH systems, six main roles can be distinguished that each consist of activities that are directly related to the DH value chain; the roles of *Producer*, *TSO*, *Heat load planner*, *DSO*, *Provider* and *Consumer*. These roles can each be fulfilled by separate stakeholders, or stakeholders can fulfil several roles as an 'integrated' stakeholder. The (organisational) characteristics of the stakeholders and the extent to which roles are distributed over different parties also shapes the functioning of DH systems. Besides these six main roles a few others can be described, of which municipal and national governments are the most significant, as they fulfil supporting but crucial roles, like issuing permits, coordinating heat planning, granting subsidies or establishing legislation.

In addition to these six roles, sixteen factors of DH system functioning are identified and divided into four categories; *technical and physical factors*, *regulatory and policy factors*, *economic factors* and *societal factors*. These factors influence the physical system, but also more abstract elements like consumer tariffs or legally obliged connection for consumers. These sixteen factors together shape DH system functioning and provide a proper foundation for describing DH system design types.

SQ2	What are the characteristics, interests and influence of the main stakeholders in a district heating system in a metropolitan area and what are the resulting requirements towards the system?

After conducting two cases studies on the DH systems of Greater Copenhagen and Greater Amsterdam and based on interviews with over twenty stakeholders and independent experts, ten different stakeholder types are identified and described;

1. *Municipality*
2. *National government*
3. *Housing association*
4. *Individual consumer*
5. *Building owner*
6. *Third-party producer*
7. *Integrated DH company*
8. *Transmission company*
9. *Heat load planner*
10. *Independent distribution company*

These ten stakeholders fulfil varying roles and combinations of roles, as they were described before. They have diverse responsibilities and tasks and they also have very different interests in and influence on the DH system's operation and design. The level of interest of a stakeholder type and its degree of influence do not always correspond; in case there is a disbalance between the two, like there is for the stakeholder type of *individual consumer* – this can become a problem to reaching a DH system design that meets the needs of all affected stakeholders. Stakeholders that own and operate a (part of the) transmission or distribution system generally have the greatest influence on design and operation, which also reflects their large interests that mainly come from the high investments they made. The two government stakeholders both have a significant influence, although the municipality on a local, system-specific level and the national government on sector-level. The three stakeholder types that 'only' connect to the system are the least influential, even though they are generally quite dependent on the DH system. Besides the level of interest and degree of influence, there also are fourteen specific interests that can be distinguished from the case studies. Some of these interests are shared by multiple stakeholder types, some are specifically important to one or two stakeholders.

In addition to the stakeholder types and interests, there also are twenty-four system requirements that are derived from the case studies and interviews. There are numerous possible requirements towards a DH system and they can be considered specific for every system, but some more or less general descriptions can be formulated for different requirements that were mentioned in interviews and followed from stakeholders' interests and experts' knowledge. The requirements all relate to multiple interests; they can help satisfy or hinder certain interests. Most of these links show mostly positive relationships to interests. Stakeholders can explore possibilities for trade-offs between system requirements, in which case combinations of requirements could achieve an acceptable total outcome for all parties. However, as not all parties have an equal influence in the planning process, an imbalance could cause problems when a DH system is aspired that (partially) satisfies all affected stakeholders. The five 'active' stakeholders (numbers 1 to 5) have a stronger influence than the five 'passive' stakeholders (numbers 6 to 10). Especially combined with the fact that many requirements either positively influence the 'active' or the 'passive' stakeholder types, this imbalance could be problematic.

SQ3 How are district heating systems currently planned by stakeholders in metropolitan areas and what are the main challenges?

When considering the planning processes in the cases of the Greater Copenhagen and Greater Amsterdam areas, it is visible that the process is organised top-down. Furthermore, the first steps in the heat planning process are on the national and regional level, the later steps of the planning process – for example on the level of an individual DH system – are organised on the local level. Municipalities are responsible for local heat plans and district-level implementation. In both cases, DH systems were originally developed in municipal ownership, but they were later (largely) privatised in Amsterdam. The public and cooperative ownership of transmission and distribution grids in Greater Copenhagen is the reason 'passive' stakeholders are considered better represented than in the mostly private DH systems in Amsterdam. However, direct (passive) stakeholder *involvement* in the planning process is limited in both cases – besides through cooperative ownership of some distribution systems. In the early stages of the heat planning process stakeholders are involved through public consultation, but in the later phases of the planning process mainly indirect representation exists. Whether individual interests are heard and promoted therefore mainly depends on ownership structure.

As both Denmark and the Netherlands are expected to go through an intensive energy and heating sector transition in following their sustainability ambitions, DH systems need to be able to adapt to changing circumstances, interests, targets and technologies. The current adaptability of both the GC and GA DH systems is considered limited. There are both physical and organisational barriers, like the dependency on large CHP- and waste plants because of financial lock-ins or the need for security of supply, or like the integration of roles that creates unwanted incentives for incumbent parties to protect their existing fossil and high temperature heat sources and therefore not lowering the system's forward temperature. These kind of barriers could harm the energy transition by reducing the DH system's ability to adapt to changes and new developments.

SQ4 What are possible district heating system design types and how do these relate to stakeholder interests and system requirements?

Looking more closely at the design of a DH system some similarities become visible, although the system's design is largely tailored to its specific context. Based on a selection of the sixteen factors of DH system functioning a framework is established that could be used to identify and classify certain design types. With these *system design factors* three steps are distinguished;

1. **District and other heating systems;** what exactly is a DH system and what is not?
2. **Technical design types;** what physical and technical variations can be distinguished?
3. **Organisational design types;** in what ways can DH systems be organised?

The technical design is based on the system design factors of *temperature regime* and *type of heat source*, the organisational design on the factors of *unbundling*, *third-party access (TPA)* and *ownership*. In order to understand how the design of a system can contribute to a sustainable heat provision for its stakeholders, it is also important to understand how these design types are related these stakeholders' interests and to the requirements that are established to satisfy these interests. The technical design of a system is mainly related to matters like heat loss, CO_2e-emissions and (technical) potential for third-party producers. Regarding the technical design; lower temperatures are regularly associated with higher potential for LT renewable sources and stronger diversification of heat sources. Larger and HT heat sources are considered to more often create lock-ins, which obstructs entry of more sustainable sources or shifting to a lower temperature. Overall, LT systems are considered to mainly benefit municipalities with renewable energy ambitions and consumers that value the sustainability performance of their heat supply. The organisational design regards to issues like competitive pressure, innovative capacity and consumer representation. Unbundling and TPA are thought to mainly benefit 'passive' stakeholders and to be a potential threat to incumbent 'active' stakeholders. Ownership mainly influences to what extent 'passive' stakeholders' interests are represented.

SQ5	What improvements can be made in the planning process of district heating systems in metropolitan areas, to support stakeholders in their transition towards a sustainable heat provision?

In order for the DH system design to contribute to the heat transition of its stakeholders, the system design framework should be equipped to facilitate the process towards the appropriate design for that specific context. Given the various challenges in the planning process – lacking (passive) stakeholder representation, disbalance of interests and influence, low adaptability of the DH system and potential obstruction of promising system designs by influential minorities of stakeholder types – improvements of the planning process are proposed. An important improvement is to actively include all stakeholders in establishing system requirements for their DH system, where each stakeholder is represented according to their level of interest. In many countries municipalities are considered the appropriate party to coordinate this process. The consequential tendering procedure that is based on these system requirements needs to be transparent to the wider public and use clear evaluation criteria that are published upfront. The procurement procedure should leave room for different system designs – both technical and organisational designs – as each system's context can result in different system requirements. Besides, more possible designs could improve the number of parties that is eligible and willing to (together) prepare a bid to establish the DH system. Societal support and (stronger) citizen participation, perhaps even in cooperative DH companies, might also benefit from stakeholder involvement and greater transparency in procurement. Lastly, the regulatory and policy framework should also support these improvements and it is therefore suggested to introduce the provision to establish (local) policies that ensure all stakeholders are involved in establishment of system requirements. Potentially existing legislation that prohibits certain technical or organisational designs is recommended to be removed or adapted. Lastly, stakeholders could potentially also be included more in drafting requirements for sector-specific legislation for DH, as this might result in different regulation than in a situation where stakeholders are not (all) consulted.

Finally, coming back to the main research question, there are a few findings that are considered most important and key to answering the research question, as given below.

RQ	How could the planning process and system design of district heating systems in metropolitan areas support stakeholders in their transition towards a sustainable heat provision?

First, the various roles that can and need to be fulfilled in a DH system in a metropolitan area are not fixed to certain stakeholder types. Several organisations can fulfil a certain role – like producing heat or distributing it to consumers – and combinations of multiple stakeholders can perform the same activities as one integrated company. Understanding, acknowledging and accepting this leaves room for a wider range of solutions to the challenge of establishing more sustainable DH systems. Secondly, there are many different stakeholder types that exist in metropolitan DH systems and they could have very different characteristics, interests and influence. However, they could share some interests and can also connect the same requirements regarding the DH system to their interests. Requirements can have a positive and negative influence on several interests at the same time, which makes alignment of interests, looking for trade-offs and finding concessions in requirements important steps to take in order to reach consensus. In order to do so and considering the fact that different stakeholders have varying degrees of influence that do not always represent their interests, it is important that all stakeholders are included proportionally in order to realise a DH system that supports all stakeholders in their transition towards sustainable heating. Lastly, there are many different technical and organisational designs possible that each have their pro's and con's. By being aware of the different possibilities, understanding the effect of combinations of system design factors on requirements and interests and by allowing for different system designs to exist, DH system designs can offer great support to all stakeholders – not as a zero-sum game, but as a compromise that finds the optimal solution for the collective.

Recommendations

Based on the analysis of this research's results, the discussion of the implications of its findings and the answers to the research question, several recommendations can be made. These recommendations are discussed in the two following sections; one considering recommendations that are (more) generally applicable, the other covering recommendations specific for Denmark or the Netherlands. Many recommendations are related to policy and regulation, as the main focus of the research is on the planning process and its influence on the DH system's design.

Generally applicable recommendations

Some recommendations that can be made are considered generally applicable to DH systems in metropolitan areas within Europe. Even given the limitations of the research's methodology, data and results and considering every country has its own physical and cultural characteristics and a different policy and regulation framework, these recommendations are thought to be relevant for all systems that fit the above scope. For each of the recommendations it is explained to whom the recommendation is mainly addressed and why.

Incorporate adaptability of DH system design into planning and procurement

In the light of the transition towards sustainable heating many countries are or will be going through, DH systems are expected to be subject to evolving needs, increasing innovation and changing circumstances. A first recommendation – mainly intended for legislators and policymakers but also relevant for (potential) DH companies – would thus be to incorporate the ability of DH systems to adapt to changing circumstances into the heat planning and procurement processes. Especially in the procurement procedure this ability should be represented, for example in the form of an evaluation criterion for the assessment of bids.

Include all stakeholder types in the planning process in general and the drafting of system requirements in particular

As was thoroughly discussed in earlier sections and chapters, several 'passive' stakeholder types face a disbalance between their degree of interest and amount of influence. Passive stakeholder types, perhaps apart from the municipality, are little or not involved in the process of heat planning in general and the establishment of system requirements in particular. Legislators and policymakers at both the national and local level should review and revise their planning process to include all stakeholder types in establishing system requirements. This way the heat planning process would become better suited to establish system designs that facilitate all stakeholders in the transition towards sustainable heating and to increase and maintain societal support for DH and the energy transition.

Increase transparency in the planning and procurement processes

When people do not know, understand or even see what is happening with their heat provision, they might be unsatisfied more easily or have no confidence in the system anymore. Increasing transparency of the planning and procurement processes, especially of the way system requirements are established and bids are assessed, is therefore recommended to build confidence and grow support for DH systems. Boosting transparency is considered a combined responsibility of policymakers of national and local governments and of DH companies that play an active role within the system that is (to be) developed.

Require local authorities to establish guidelines for stakeholder involvement in establishing requirements

Policymakers and legislators of the national government are recommended to work towards requiring – by law – municipalities and other local authorities to establish guidelines for the involvement of all stakeholder types in drafting system requirements. Without a formal requirement to establish these guidelines and to clarify how stakeholder involvement should be implemented, it will probably result in some areas where stakeholder are in fact involved in the planning process and other areas where passive stakeholder types have no influence on system requirements at all. As this involvement is of high importance, national government legislators should set equal standards for all areas.

Accept different system designs, based on the system requirements that are collectively established in heat planning

The last recommendation that is generally applicable is an important one. Legislators of the national government are recommended to allow for varying DH system designs, both for the technical and organisational designs. As DH is a relatively local activity its system design should also be able to consider the local characteristics and differences between areas. In order to be able to fit the DH system's design to an area's particular context – like the existing building stock – and its stakeholders specific needs. By not allowing different technical and organisational design types to exist, the DH system design cannot be customised for those particular needs. Differentiation of system designs could also attract competition and stimulate innovation. Regulation that prohibits certain configurations of design or puts restrictions on system design factors is therefore considered harmful to a properly functioning DH sector. It is therefore strongly recommended to not rigidly focus on one or only a few possibilities for the system design.

Case-specific recommendations

Besides recommendations that are generally applicable, there also are a few case-specific recommendations, aiming to support stakeholders in both the Greater Copenhagen and Greater Amsterdam areas.

Greater Copenhagen

There is one important recommendation for the DH sector in Denmark and Danish policy. This regards the risk of reaching a situation of lock-in, which to a certain extent already seems to be the case due to the very high dependency on and strong cost competitiveness of CHP- and waste incineration plants. The Greater Copenhagen DH system is one of the largest systems in the world and generally considered to be functioning quite well. However, several stakeholders and experts explained the wish to both integrate more decentral heat production and to diversify sources, as Copenhagen sees biomass as a transition fuel but seems to be first fully transitioning towards the use of biomass. The current system design – on a organisational but mostly on a technical level – seems to raise a barrier to these two goals. It is therefore recommended to the DH companies and their municipal and cooperative owners to aim to reduce the dependency on these large scale and high-temperature sources. Without decreasing this dominance and the impact these sources have on e.g. the system temperature, a more decentralised and sustainable DH system is expected to be harder to realise.

Greater Amsterdam

Several recommendations can be made for the DH system of the Greater Amsterdam area, but also for the Dutch DH sector in general. A very important recommendation relates to the Heat Supply Act (*Warmtewet*) that is currently put out for consultation. Regarding the Warmtewet, its legislators are strongly recommended to allow for different system designs to exist. However, the latest version of the draft Warmtewet showed to not allow other organisational designs, but only accept differentiation on technical design types.

Another, perhaps even more important recommendation also relates to the Warmtewet, but focuses on the involvement of stakeholders in the heat planning process and more specifically in the establishment of system requirements. This recommendation strongly resembles one of the generally applicable recommendations of the previous section, but is considered different and more specific for the Netherlands. It is recommended – again; for legislators that work on the Warmtewet – to take (passive) stakeholder involvement in drafting system requirements into account in revising the current Warmtewet. As legislative procedures often take years to be finalized, it would be wise to assess the degree to which the Dutch legislative structure enables the Warmtewet to incorporate this recommendation in the new legislation. Given the high climate ambitions of the Dutch government and the city of Amsterdam and the growing DH sector in the coming years, it is recommended to already start with amending the Warmtewet.

Lastly, two other recommendations consider transparency and tariffs. Experiences in Greater Copenhagen and Denmark show that transparency of DH tariffs is considered one of the main drivers behind public acceptance, societal support and citizen participation. Also, benchmarking different yet comparable DH systems could increase consumer confidence and boost understanding by stakeholders. It is therefore recommended that Dutch policymakers, regulators and – again – legislators consider the possibilities to increase transparency of DH tariffs and to (legally) require benchmarking of DH systems.

Suggestions for future research

This last section makes a few suggestions for future research, by building on the implications, limitations and recommendations of this research. There are three suggestions for future studies, all briefly discussed below.

1. The first suggestion would be related to one of the main recommendations of this research, namely to involve all stakeholder types – including the passive types – in drafting system requirements. This recommendation is made, but it is still unclear what ways exist to implement this recommendation and which method of stakeholder involvement in drafting system requirements is preferred. Also, does this depend on the context of the (proposed) system? Involvement of all stakeholder could perhaps be studied in a practical situation.
2. A second suggestion for future research is slightly related to the above. It would be to focus on one single stakeholder type and study the interests and influence of this particular type, the way these interests are represented and to what extent these are included in the process of drafting system requirements. Doing this for all ten identified stakeholder types would add to the understanding of how many parties are in fact really involved in establishing these requirements. It could also be possible to investigate whether there are factors

of the (potential) DH system – like size, or whether or not there already was a DH system nearby – that influence the way and degree of involvement of all of these stakeholder types.

3. A third suggestion would be to zoom in on current steps in the planning process and reflect on the way how and degree to which stakeholder types are directly involved or indirectly represented in each of these steps. This would then more clearly define the planning process, provide a better overview of 'where it goes wrong' in stakeholder involvement – given the fact that stakeholder involvement seems to be more 'open' and easy in the earlier steps of the planning process, but only when the heat planning is still very high-level and far from specifically relevant for a certain DH area.

References

Åberg, M., Fälting, L., & Forssell, A. (2016). Is Swedish district heating operating on an integrated market? – Differences in pricing, price convergence, and marketing strategy between public and private district heating companies. *Energy Policy*, 222-232.

Adams, W. C. (2015). Conducting semi-structured interviews. In K. E. Newcomer, H. P. Hatry, & J. S. Wholey, *Handbook of Practical Program Evaluation* (pp. 492-505). San Francisco: Jossey-Bass.

AEB Amsterdam. (2018). *Jaarverslag 2017.* Amsterdam: AEB Amsterdam.

AEB Amsterdam. (2020). *Over AEB*. Hentet fra AEB Amsterdam: https://www.aebamsterdam.nl/over-aeb/

Akerboom, S., Van der Linden, F., & Pront-Van Bommel, S. (2014). *Notitie bij de workshop warmtenetten: een analyse van de warmtewet.* Amsterdam: Universiteit van Amsterdam.

Amsterdam Economic Board. (2016). *Programma Warmte en Koude in de Metropoolregio Amsterdam.* Amsterdam: Amsterdam Economic Board.

Ancona, M. A., Branchini, L., De Pascale, A., & Melino, F. (2015). Smart District Heating: Distributed Generation Systems' Effects on the Network. *The 7th International Conference on Applied Energy – ICAE2015* (pp. 1208-1213). Abu Dhabi, UAE: Elsevier.

ARC. (2020). *Alt med affald*. Retrieved from ARC Amager Ressource Center: https://www.a-r-c.dk/om-arc/arc-alt-med-affald

ARGO. (2020). *Om os*. Retrieved from ARGO: https://argo.dk/om-os/

Artogis. (2020). *Forsyningsområde*. Retrieved from Vestforbrænding: https://webgis.vestfor.dk/forsyningsomr/?guest=true

ATLAS.ti Scientific Software Development GmbH. (2020). ATLAS.ti 8 for Windows 10. Berlin, Germany.

Autoriteit Consument & Markt. (2018, December 21). *Besluit tot vaststelling van de maximumprijs en de berekening van de eenmalige aansluitbijdrage en het meettarief warmteverbruik per 1 januari 2019.* Den Haag: ACM.

Autoriteit Consument & Markt. (2020). *Levering van warmte*. Retrieved from Autoriteit Consument & Markt: https://www.acm.nl/nl/onderwerpen/energie/energieleveranciers/levering-van-warmte/ik-wil-warmte-leveren-wat-moet-ik-doen

Averfalk, H., Ingvarsson, P., Persson, U., Gong, M., & Werner, S. (2017). Large heat pumps in Swedish district heating systems. *Renewable and Sustainable Energy Reviews*, 1275-1284.

AVROTROS. (2017, September 11). *Stadsverwarming duurder dan gasaansluiting.* Retrieved from Radar: https://radar.avrotros.nl/uitzendingen/gemist/item/stadsverwarming-duurder-dan-gasaansluiting/

AVROTROS. (2019, November 23). *Hele wijk in Purmerend van het gas af, op 6 bewoners na: 'Ik bepaal zelf hoe ik mijn huis verwarm'.* Retrieved from EenVandaag: https://eenvandaag.avrotros.nl/item/hele-wijk-in-purmerend-van-het-gas-af-op-6-bewoners-na-ik-bepaal-zelf-hoe-ik-mijn-huis-verwarm/

AVROTROS. (2019, November 18). *Maandlasten warmte-koudeopslag extreem hoog*. Retrieved from Radar: https://radar.avrotros.nl/uitzendingen/gemist/item/maandlasten-warmte-koudeopslag-extreem-hoog/

BIOFOS. (2020). *Om os*. Retrieved from BIOFOS: https://biofos.dk/om-os/

Birnbaum, A. (2019, May 28). Interview Høje Taastrup Fjernvarme. (S. Wiegerinck, Interviewer)

Blom, M., Rozema, J., & Van der Veen, F. (2019). *Rendementsmonitor warmteleveranciers 2017 en 2018.* Delft: CE Delft.

Borch, K., Nyborg, S., Clausen, L. T., & Jorgensen, M. S. (2017). Wind2050 – a transdisciplinary research partnership about wind energy. In L. Holstenkamp, & J. Radtke, *Handbuch Energiewende und Partizipation* (pp. 873-894). Wiesbaden: Springer VS.

Bryman, A. (2012). *Social Research Methods.* New York: Oxford University Press.

Buffa, S., Cozzini, M., D'Antoni, M., Baratieri, M., & Fedrizzi, R. (2019). 5th generation district heating and cooling systems: A review of existing cases in Europe. *Renewable and Sustainable Energy Reviews*, 504-522.

Buijck, M. (2. October 2019). Interview Vattenfall NL. (S. Wiegerinck, Interviewer)

C40 Cities. (2016). *Good practice guide - District Energy.* New York City: C40 Cities.

CBS. (2020, January). *Energieverbruik particuliere woningen; woningtype en regio's*. Retrieved from CBS Statline: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/81528NED/table?ts=1592859375729

CBS. (2020, February 26). *Kerncijfers wijken en buurten 2017*. Retrieved from CBS Statline: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83765NED/table?ts=1593441986472&fromstatweb=true

CBS. (2020, May 27). *Kerncijfers wijken en buurten 2019*. Retrieved from CBS Statline: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/84583NED/table?ts=1593443834053

CBS. (2020, February 11). *Voorraad woningen; eigendom, type verhuurder, bewoning, regio*. Retrieved from CBS Statline: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/82900NED/table?fromstatweb

CBS Statline. (2019, May 17). Bevolking op 1 januari en gemiddeld; geslacht, leeftijd en regio. Den Haag, Zuid-Holland, Netherlands.

Cechini, F., Ice, R., & Binkley, D. (2009). *Systems Engineering Guidebook for Intelligent Transportation Systems.* Sacramento, CA: Federal Highway Administration.

Chittum, A., & Østergaard, P. A. (2014). How Danish communal heat planning empowers municipalities and benefits individual consumers. *Energy Policy*, 465-474.

Cho, J. Y., & Lee, E.-H. (2014). Reducing Confusion about Grounded Theory and Qualitative Content Analysis: Similarities and Differences. *The Qualitative Report*, 1-20.

City of Copenhagen. (2012). *CPH 2025 Climate Plan.* Copenhagen: Technical and Environmental Administration.

Collier, U. (2018). *Renewable heat policies: Delivering clean heat solutions for the energy transition.* Paris: International Energy Agency.

CTR. (2009). *Worldclass, climate-friendly heating.* Frederiksberg: CTR.

CTR. (2014). *District Heating - Close Up.* Frederiksberg: CTR.

CTR. (2019). *Årsregnskab og beretning 2018.* Frederiksberg: CTR.

CTR. (2020). *Årsregnskab og beretning 2019.* Frederiksberg: CTR.

Danish Energy Agency. (2015). *District Heating - Danish experiences.* Copenhagen: Danish Energy Agency.

Danish Energy Agency. (2017). *Regulation and planning of district heating in Denmark.* Copenhagen: Danish Energy Agency.

Danish Energy Agency. (2019). *Energy Statistics 2017.* Copenhagen: Danish Energy Agency.

Danish Energy Agency. (2020). *Informal input to Dutch Heat Act.* Copenhagen: Danish Energy Agency.

Dansk Fjernvarme. (2019, October 31). *Fjernvarmeprisen i Danmark 2019*. Retrieved from Dansk Fjernvarme: https://www.danskfjernvarme.dk/viden/statistik-subsection/varmeprisstatistik/fjernvarmeprisen-i-danmark-2019

Danske Love. (2020). *Varmeforsyningsloven*. Retrieved from Danske Love: https://danskelove.dk/varmeforsyningsloven

DBDH. (2020). *District heating in Denmark - District heating history*. Retrieved from DBDH: https://dbdh.dk/dhc-in-denmark/district-heating-history/

De Gelderlander. (2019, June 4). *PvdA Nijmegen start petitie tegen monopolie Nuon op warmtenet*. Retrieved from De Gelderlander: https://www.gelderlander.nl/nijmegen/pvda-nijmegen-start-petitie-tegen-monopolie-nuon-op-warmtenet~a4b1ef25/

De Ronde, K. (2019, November 7). *Vattenfall voorziet restwarmte-leverend datacenterbedrijf van stroom*. Retrieved from Energeia: https://energeia.nl/energeia-artikel/40085015/vattenfall-voorziet-restwarmte-leverend-datacenterbedrijf-van-stroom

Den Hartog, R. (2014, September). *Stadsverwarming en de Rosariumbuurt – Een gesprek met Arno Harting, gemeente Utrecht.* Retrieved from Energie-U: https://www.energie-u.nl/wp-content/uploads/2016/05/Hartog-R.-den-2014-Stadsverwarming-en-de-Rosariumbuurt.-Een-gesprek-met-Arno-Harting-gemeente-Utrecht..pdf

Den Ouden, B., Hoeksema, L. H., & Graafland, P. (2015). *Verduurzaming gebouwde omgeving door open warmtenetten.* Utrecht: Berenschot Groep B.V.

Department for Business, Energy & Industrial Strategy. (2020). *International Review of Heat Network Market Frameworks.* London: Government of the United Kingdom.

District heating and cooling optimization and enhancement – Towards integration of renewables, storage and smart grid. (2017). *Renewable and Sustainable Energy Reviews*, 281-294.

Donnellan, S., Burns, F., Alabi, O., & Low, R. (2018). *Lessons from European regulation and practice for Scottish district heating regulation.* Edinburgh: ClimateXChange.

DWA. (2020). *Transitievisie Warmte Beemster en Purmerend - Plan van aanpak.* Purmerend: Gemeente Purmerend.

Ecofys. (2015). *Een evaluatie van open warmtenetten.* Utrecht: Efocys.

Ecorys. (2016). *Evaluatie Warmtewet en toekomstig marktontwerp warmte.* Rotterdam: Ecorys.

Eerste Kamer der Staten-Generaal. (2013). *Novelle Warmtewet*. Retrieved from Eerste Kamer: https://www.eerstekamer.nl/wetsvoorstel/32839_novelle_warmtewet

Eisenhardt, K. M. (1989). Building Theories from Case Study Research. *Academy of Management Review*, 532-550.

Endl, A. (2017). Addressing "Wicked Problems" through Governance for Sustainable Development - A Comparative Analysis of National Mineral Policy Approaches in the European Union. *Sustainability*, 1830.

Energie Beheer Nederland B.V. (2018, October 23). *Onderzoek mogelijkheden Ultradiepe aardwarmte in Nederland gaat van start*. Retrieved from EBN B.V.: https://www.ebn.nl/onderzoek-mogelijkheden-ultradiepe-aardwarmte-in-nederland-gaat-van-start/

Enpuls. (2020, March 11). *ENGIE warmteleverancier slim energienet Roermond.* Retrieved from Enpuls: https://www.enpuls.nl/media/1htfhsn2/persbericht-ser_engie-warmteleverancier_final.pdf

European Union. (2019, March 29). EU Vocabularies. Luxembourg, Luxembourg.

Faulconbridge, I., & Ryan, M. J. (2018). *Systems Engineering Practice.* Canberra: Argos Press.

Firan. (2020). *Collectief warmtenet Haarlem Schalkwijk*. Retrieved from Firan: https://www.firan.nl/cases/collectief-warmtenet-haarlem-schalkwijk/

Firan. (2020, March 10). *Open warmtenet Zaanstad benut warmte van biomassacentrale*. Retrieved from Firan: https://www.firan.nl/cases/open-warmtenet-zaanstad-met-warmte-van-biomassacentrale/

Firan. (2020, July 8). *Open warmtenet Zaanstad benut warmte van biomassacentrale*. Retrieved from Firan: https://www.firan.nl/cases/open-warmtenet-zaanstad-met-warmte-van-biomassacentrale/

Folke, P. (2019, May 27). Interview Varmelast. (S. Wiegerinck, Interviewer)

FORESIGHT Climate & Energy. (26. April 2019). *The path to emissions-free district heating in Denmark*. Hentet fra FORESIGHT Climate & Energy: https://foresightdk.com/the-path-to-emissions-free-district-heating-in-denmark/

FORS A/S. (2019). *Ledelses- & Ansvarlighedsrapport 2018.* Roskilde: FORS A/S.

Forsyningstilsynet. (2019). *Prisstatistik for Fjernvarmeselskaber pr. August 2019.* Valby: Forsyningstilsynet.

Forsyningstilsynet. (2020). *About us*. Hentet fra Forsyningstilsynet: https://forsyningstilsynet.dk/about-us

Frederiksberg Forsyning. (2020). *Om os*. Retrieved from Frederiksberg Forsyning: https://www.frb-forsyning.dk/om-os

Frederiksberg Forsyning. (2020). *Varme*. Retrieved from Frederiksberg Forsyning: https://www.frb-forsyning.dk/forside/varme

Galindo Fernández, M., Roger-Lacan, C., Gährs, U., & Aumaitre, V. (2016). *Efficient district heating and cooling systems in the EU - Case studies analysis, replicable key success factors and potential policy implications.* Luxembourg: European Union.

Geldhof, R., Nieuwenhuis, S., Oudejans, J., & Smoor, P.-P. (2020). *Transitievisie Warmte.* Amsterdam: Gemeente Amsterdam.

Gemeente Amsterdam. (2020). *Nieuw Amsterdams Klimaat: Routekaart Amsterdam Klimaatneutraal 2050.* Amsterdam: Gemeente Amsterdam.

Gemeente Haarlem. (2019). *Warmtenet Schalkwijk*. Retrieved from Gemeente Haarlem: https://www.haarlem.nl/warmtenet-schalkwijk/

Gentofte Gladsaxe Fjernvarme. (2020). *Om Gentofte Gladsaxe Fjernvarme*. Retrieved from Gentofte Gladsaxe Fjernvarme: https://gentoftefjernvarme.dk/privat/om-os/

Gerring, J. (2006). Single-Outcome Studies: A Methodological Primer. *International Sociology*, 707-734.

Gorroño-Albizu, L., Sperling, K., & Djørup, S. (2019). The past, present and uncertain future of community energy in Denmark: Critically reviewing and conceptualising citizen ownership. *Energy Research & Social Science*, Vol. 57, 101231.

Government of Sweden. (2011). *Fjärrvärme i konkurrens - Betänkande av TPA-utredningen.* Stockholm: Government of Sweden.

Gronheit, P. E., & Mortensen, B. G. (2016). District heating as the infrastructure for competition among fuels and technologies. *Journal of Energy Challenges and Mechanics*, 64-69.

Gugler, K., Rammerstorfer, M., & Schmitt, S. (2013). Ownership unbundling and investment in electricity markets - A cross country study. *Energy Economics*, 702-713.

Hamer. (2019, April 17). *Warmte / Koude uitwisseling datacenter NL|DC Aalsmeer*. Retrieved from Hamer: https://www.hamer.net/nieuws/warmte-koude-uitwisseling-datacenter-nldc-aalsmeer/

Hatzl, S., Seebauer, S., Fleiß, E., & Posch, A. (2016). Market-based vs. grassroots citizen participation initiatives in photovoltaics: A qualitative comparison of nice development. *Futures*, 57-70.

Heat Roadmap Europe. (2020). *Pan-European Thermal Atlas 4.3*. Retrieved from Heat Roadmap Europe: https://heatroadmap.eu/peta4/

Henriksen, T. C. (2019, May 27). Interview Dansk Energi. (S. Wiegerinck, Interviewer)

Het Financieele Dagblad. (2020, April 2). *Kabinet wil productie kolencentrales flink terugschroeven vanwege 'Urgenda'*. Retrieved from FD: https://fd.nl/economie-politiek/1340230/kabinet-wil-productie-kolencentrales-flink-terugschroeven-vanwege-urgenda

Het Parool. (2020, June 19). *Diemen vraagt Kamer om tegenhouden biomassacentrale*. Retrieved from Het Parool: https://www.parool.nl/amsterdam/diemen-vraagt-kamer-om-tegenhouden-biomassacentrale~b6cb00dc/

HIER verwarmt. (2018, November 21). *Samen met je buurt aan de slag: het Ramplaankwartier in Haarlem*. Retrieved from HIER verwarmt: https://www.hierverwarmt.nl/samen-met-je-buurt-aan-slag-het-ramplaankwartier-in-haarlem

HOFOR. (2016). *District Heating in Copenhagen: energy-efficient, low-carbon, and cost-effective.* Copenhagen: HOFOR.

HOFOR. (2018). *HOFOR Greater Copenhagen Utility.* Copenhagen: HOFOR.

Høje Taastrup Fjernvarme. (2020). *Organisationen*. Retrieved from HTF: https://www.htf.dk/organisationen

Holm, K. E. (2019, June 6). Interview CTR. (S. Wiegerinck, Interviewer)

Honoré, K. (2019, June 3). Interview HOFOR. (S. Wiegerinck, Interviewer)

Hood, J. C. (2007). Orthodoxy vs. Power: The Defining Traits of Grounded Theory. I A. Bryant, & K. Charmaz, *The SAGE Handbook of Grounded Theory* (s. 151-164). London: SAGE Publications Ltd.

Hoogervorst, N. (2017). *Toekomstbeeld Klimaatneutrale warmtenetten in Nederland.* Den Haag: Planbureau voor de Leefomgeving.

Hsieh, H.-F., & Shannon, S. E. (2005). Three Approaches to Qualitative Content Analysis. *Qualitative Health Research*, 1277-1288.

IEA. (2017, November 5). *Danish Energy Agreement for 2012-2020*. Retrieved from IEA Policies Database: https://www.iea.org/policies/606-danish-energy-agreement-for-2012-2020

INCOSE. (2006). *Systems Engineering Handbook.* Hoboken: John Wiley and Sons.

IRENA. (2016). *Renewable Energy in Cities.* Abu Dhabi: International Renewable Energy Agency (IRENA).

IRENA. (2017). *Renewable Energy in District Heating and Cooling: A Sector Roadmap for REmap.* Abu Dhabi: International Renewable Energy Agency.

IRENA. (2018). *Global Energy Transformation: A roadmap to 2050.* Abu Dhabi: International Renewable Energy Agency.

Janssen, B. (2015). *De consument en de collectieve warmtevoorziening - Een moeizaam verstandshuwelijk.* Amsterdam: ASRE.

Jessen, K. (2017). DISTRICT HEATING In The Danish Energy System. Kolding, Denmark.

Joosse, B. (2019, August 21). *Datacenter bespaart tonnen CO2 door uitwisseling warmte*. Retrieved from Duurzaam Bedrijfsleven: https://www.duurzaambedrijfsleven.nl/energie/32211/datacenter-uitwisseling-warmte

KAB. (2020). *Energidrift*. Retrieved from KAB Bolig: https://www.kab-bolig.dk/om-kab/ydelser-og-raadgivning/energidrift

Kamp, H. G. (2015, July 1). *Brief van de Minister van Economische Zaken.* Retrieved from Officiële bekendmakingen: https://zoek.officielebekendmakingen.nl/kst-30196-348.html

Kamp, H. G. (2017). *Kamerbrief Warmtevisie.* Den Haag: Ministerie van Economische Zaken.

Kamp, H. G. (2017, May 24). *Wijziging van de Warmtewet (wijzigingen naar aanleiding van de evaluatie van de Warmtewet).* Retrieved from Officiële bekendmakingen: https://zoek.officielebekendmakingen.nl/kst-34723-3.html

Klima-, Energi- og Forsyningsministeriet. (2018). *Energiaftale.* Copenhagen: Klima-, Energi- og Forsyningsministeriet.

Klimaatberaad. (3. March 2018). *Samenstelling sectortafels Klimaatakkoord bekend*. Hentet fra Klimaatakkoord: https://www.klimaatakkoord.nl/actueel/nieuws/2018/03/20/samenstelling-sectortafels-klimaatakkoord-bekend

Køge Fjernvarme. (2020). *Organisationen*. Hentet fra Køge Fjernvarme: https://www.koegefjernvarme.dk/om-koege-fjernvarme/organisationen

Køge Kommune. (2016). *Strategisk Energiplan for Køge Kommune.* Køge: Køge Kommune.

Kotlowski, A. (2007). Third-Party Access Rights in the Energy Sector: A Competition Law Perspective. *Utilities Law Review*, 101-109.

Künneke, R., & Fens, T. (2007). Ownership unbundling in electricity distribution: The case of The Netherlands. *Energy Policy*, 1920-1930.

Lauersen, B. (2019, November 15). *District Energy in Denmark*. Retrieved from Euroheat & Power: https://www.euroheat.org/knowledge-hub/district-energy-denmark/

Li, H., & Nord, N. (2018). Transition to the 4th generation district heating - possibilities, bottlenecks, and challenges. *16th International Symposium on District Heating and Cooling, DHC2018* (pp. 483-498). Hamburg, Germany: Elsevier.

Li, H., & Wang, S. J. (2014). Challenges in Smart Low-Temperature District Heating Development. *Energy Procedia*, 1472-1475.

Liander N.V. (2019). *Liander N.V. Jaarbericht 2018.* Arnhem: Liander N.V.

Lillethorup, B. (2019, June 3). Interview Ørsted. (S. Wiegerinck, Interviewer)

Loogman, H. (2020). *Biomassacentrale*. Retrieved from Opgewekt in Purmerend: http://www.opgewektinpurmerend.com/stg_aaf79/a-biomassacentrale/

Lund, H. T. (2019, May 22). Interview KAB. (S. Wiegerinck, Interviewer)

Lund, H., Möller, B., Mathiesen, B. V., & Dyrelund, A. (2010). The role of district heating in future renewable energy systems. *Energy*, 1381-1390.

Lund, H., Østergaard, P. A., Chang, M., Werner, S., Svendsen, S., Sorknæs, P., . . . Möller, B. (2018). The status of 4th generation district heating: Research and results. *Energy*, 147-159.

Lund, H., Werner, S., Wiltshire, R., Svendsen, S., Thorsen, J. E., Hvelplund, F., & Mathiesen, B. V. (2014). 4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems. *Energy*, 1-11.

Lund, R., & Persson, U. (2016). Mapping of potential heat sources for heat pumps for district heating in Denmark. *Energy*, 129-138.

Magnusson, D. (2012). Swedish district heating - A system in stagnation: Current and future trends in the district heating sector. *Energy Policy*, 449-459.

Magnusson, D. (2013). *District Heating in a Liberalized Energy Market: A New Order?* Linköping: The Department of Thematic Studies – Technology and Social Change, Linköping University.

Magnusson, D. (2016). Who brings the heat? From municipal to diversified ownership in the Swedish district heating market post-liberalization. *Energy Research & Social Science*, 198-209.

Marselis, I., & Hisschemöller, M. (2018). *'Het moet niet te avontuurlijk worden' - Een onderzoek naar de institutionele barrières voor een wijkgebonden warmtevoorziening in Amsterdam.* Rotterdam: DRIFT.

Mazhar, A. R., Liu, S., & Shukla, A. (2018). A state of art review on the district heating systems. *Renewable and Sustainable Energy Reviews*, 420-439.

McDonald, O. (2019, May 6). *Gemeente Diemen dient via omweg bezwaar in tegen biomassacentrale Vattenfall*. Retrieved from Energeia: https://energeia.nl/energeia-artikel/40080709/gemeente-diemen-dient-via-omweg-bezwaar-in-tegen-biomassacentrale-vattenfall

McDonald, O. (2019, February 13). *Provincie Gelderland wil af van monopoliepositie Nuon op warmtenet*. Retrieved from Energeia: https://energeia.nl/energeia-artikel/40078210/provincie-gelderland-wil-af-van-monopoliepositie-nuon-op-warmtenet

McDonald, O. (2019, May 31). *'Succes Deense warmtebedrijven ligt vooral aan transparantie'*. Retrieved from Energeia: https://energeia.nl/energeia-artikel/40081120/succes-deense-warmtebedrijven-ligt-vooral-aan-transparantie

McDonald, O. (2020, March 17). *Verkoop afvalcentrale AEB uitgesteld; toekomst stadswarmtebedrijf nog onbeslist*. Retrieved from Energeia: https://energeia.nl/energeia-artikel/40087302/verkoop-aeb-uitgesteld-toekomst-stadswarmtebedrijf-nog-onbeslist

MeerEnergie. (2019, November 11). *Ons plan*. Retrieved from MeerEnergie: https://meerenergie.amsterdam/plannen/

Mendonça, M., Lacey, S., & Hvelplund, F. (2009). Stability, participation and transparency in renewable energy policy: Lessons from Denmark and the United States. *Policy and Society*, 379-398.

Menkveld, M., Matton, R., Segers, R., Vroom, J., & Kremer, A. M. (2017). *Monitoring warmte 2015.* Petten: ECN.

Möller, B., Wiechers, E., Persson, U., Grundahl, L., & Connolly, D. (2018). Heat Roadmap Europe: Identifying local heat demand and supply areas with a European thermal atlas. *Energy*, 281-292.

Moolenaar, S., & Opten, N. (2019, February 11). *Klinkt goed, zo'n warmtenet. Waarom zijn klanten dan toch ontevreden?* Retrieved from De Gelderlander: https://www.gelderlander.nl/arnhem/klinkt-goed-zo-n-warmtenet-waarom-zijn-klanten-dan-toch-ontevreden~ab2bb738/

Mostashari, A., & Sussman, J. (2004). Engaging Stakeholders in Engineering Systems Representation and Modeling.

Nationaal Energiebespaarfonds. (3. February 2020). *Warmtefonds van start bij het Nationaal Energiebespaarfonds*. Hentet fra Nationaal Energiebespaarfonds: https://www.energiebespaarlening.nl/warmtefonds-van-start-bij-het-nationaal-energiebespaarfonds/

Natuur & Milieu. (2018). *Warmtenetten in de energietransitie.* Utrecht: Natuur & Milieu.

Negassi, S., & Hung, T.-Y. (2014). The nature of market competition and innovation: does competition improve innovation output? *Economics of Innovation and New Technology*, 63-91.

Netbeheer Nederland. (2019). *Basisinformatie over energie-infrastructuur.* Den Haag: Netbeheer Nederland.

Nicolaï, A. (2019, August 28). Interview MeerEnergie. (S. Wiegerinck, Interviewer)

Nijpels, E. (2018). *Ontwerp van het Klimaatakkoord.* Den Haag: Klimaatberaad.

Nimb, N.-P., & Danekilde, C. S. (4. June 2019). Interview Roskilde Kommune. (S. Wiegerinck, Interviewer)

NOS. (2020, June 9). *D66 en ChristenUnie: geen geld voor nieuwe biomassacentrales*. Retrieved from NOS: https://nos.nl/artikel/2336735-d66-en-christenunie-geen-geld-voor-nieuwe-biomassacentrales.html

Odgaard, O. (2019, January 11). *District Heating in Denmark: Long-term goals (2030/2050) and implementation tools.* Retrieved from Lithuanian District Heating Association: https://www.lsta.lt/files/events/2018-06-11_Varsuva/03_Ole%20Odgaard.pdf

OECD. (2012). *Redefining "Urban": A New Way to Measure Metropolitan Areas.* Paris: OECD Publishing.

OECD. (2012). *Redefining "Urban": A New Way to Measure Metropolitan Areas.* Paris: OECD Publishing.

OECD. (2019, August 2). *Metropolitan areas.* Retrieved from OECD.Stat: https://stats.oecd.org/Index.aspx?DataSetCode=CITIES

Opten, N. (2019, March 11). *Ellen uit Arnhem weigert verplichte stadsverwarming, toch moet ze er 4.400 euro voor betalen*. Retrieved from De Gelderlander: https://www.gelderlander.nl/arnhem/ellen-uit-arnhem-weigert-verplichte-stadsverwarming-toch-moet-ze-er-4-400-euro-voor-betalen~a4eb27a8/

Orgaworld. (2020). *Amsterdam: Greenmills anaerobe vergistingsfabriek*. Retrieved from Orgaworld: https://orgaworld.nl/meer-over-ons-bedrijf/onze-locaties/amsterdam-greenmills

Overbye, P. M. (2019, October 1). *Heat and Fuel Sources of the Future.* Retrieved from District Heating Antwerpen: https://www.districtheatingantwerpen.be/images/presentaties/007%20PERNILLE%20OVERBYE%202%20workshop%20warmtenetten%2022%20nov%202018.pdf

Oxford University Press. (2020). *Dictionaries*. Hentet fra Oxford Learner's Dictionaries: https://www.oxfordlearnersdictionaries.com/definition/english/factor_1?q=factor

Patil, A., Ajah, A., & Herder, P. (2009). Recycling industrial waste heat for sustainable district heating: a multi-actor perspective. *International Journal of Environmental Technology and Management*, 412-426.

Patronen, J., Kaura, E., & Torvestad, C. (2017). *Nordic heating and cooling - Nordic approach to EU's Heating and Cooling Strategy.* Copenhagen: Nordic Council of Ministers.

Pauschinger, T. (2016). Solar thermal energy for district heating. In R. Wiltshire, *Advanced District Heating and Cooling (DHC) Systems* (pp. 99-120). Cambridge, United Kingdom: Woodhead Publishing.

PBL. (2020). *Stimuleringsregeling Duurzame Energietransitie (SDE++)*. Hentet fra Planbureau voor de Leefomgeving: https://www.pbl.nl/sde

Persson, U. (2015). *District heating in future Europe: Modelling expansion potentials and mapping heat synergy regions.* Göteborg: Chalmers University of Technology.

Pettigrew, A. M. (1990). Longitudinal Field Research on Change: Theory and Practice. *Organization Science*, 267-292.

Plumer, B., & Popovich, N. (2018, December 7). The World Still Isn't Meeting Its Climate Goals. *The New York Times*.

Pollitt, M. (2008). The arguments for and against ownership unbundling of energy transmission networks. *Energy Policy*, 704-713.

Pöyry Management Consulting Oy. (2018). *Third-party Access to District Heating Networks.* Vantaa: Pöyry Management Consulting Oy.

Programma Aardgasvrije Wijken. (2020). *Regie en organisatie*. Retrieved from Programma Aardgasvrije Wijken: https://www.aardgasvrijewijken.nl/klp/ro/default.aspx

Rambøll. (2012). *District Heating in the Copenhagen Region.* Retrieved from Ramboll: https://dk.ramboll.com/-/media/files/rgr/documents/markets/energy/def/district-heating-system-copenhagen.pdf

Rambøll. (2020). *District heating system in the Copenhagen Region*. Retrieved from Ramboll: https://ramboll.com/projects/group/district-heating-system-in-the-copenhagen-region

Ranzijn, A. (2020, April 29). *Stadsloket Oost besmeurd door tegenstanders biomassacentrale*. Retrieved from Het Parool: https://www.parool.nl/amsterdam/stadsloket-oost-besmeurd-door-tegenstanders-biomassacentrale~b2ad52ad/?utm_source=link&utm_medium=app&utm_campaign=shared%20content&utm_content=free

Rekenkamer Amsterdam. (2018). *Grip op Westpoort Warmte (onderzoeksrapport).* Amsterdam: Rekenkamer Amsterdam.

Rekenkamer Amsterdam. (2019). *Verduurzaming warmtevoorziening met warmtenetten.* Amsterdam: Rekenkamer Amsterdam.

Rijksdienst voor Ondernemend Nederland. (2020). *Fiscale regeling EIA helpt duurzame investeringen in warmtenetten*. Retrieved from RVO: https://www.rvo.nl/actueel/praktijkverhalen/fiscale-regeling-eia-helpt-duurzame-investeringen-warmtenetten

Rijksoverheid. (17. June 2013). *Warmtewet*. Hentet fra Wettenbank: https://wetten.overheid.nl/BWBR0033729/2020-01-01

Rijksoverheid. (2019, September 9). *Gasunie wordt onafhankelijk warmtetransportbeheerder 'Leiding door het Midden' en 'Vondelingenplaat'*. Retrieved from Rijksoverheid: https://www.rijksoverheid.nl/actueel/nieuws/2019/09/09/gasunie-wordt-onafhankelijk-warmtetransportbeheerder-leiding-door-het-midden-en-vondelingenplaat%E2%80%99

Rijksoverheid. (2019). *Klimaatakkoord.* Den Haag: Rijksoverheid.

Rijksoverheid. (2020, March 23). *200 Miljoen subsidie voor overstap huurwoningen op warmtenet*. Retrieved from Rijksoverheid: https://www.rijksoverheid.nl/actueel/nieuws/2020/03/23/200-miljoen-subsidie-voor-overstap-huurwoningen-op-warmtenet

Rønne, A., & Nielsen, F. G. (2019). Consumer (Co-)Ownership in Renewables in Denmark. In J. Lowitzsch, *Energy Transition: Financing Consumer Co-Ownership in Renewables* (pp. 223-244). London: Palgrave Macmillan.

SAB. (2020). *Om afdelingsbestyrelser*. Retrieved from SAB Bolig: http://www.sab-bolig.dk/beboervalgt/om-afdelingsbestyrelser

Sacchi, R., & Ramsheva, Y. K. (2017). The effect of price regulation on the performances of industrial symbiosis: a case study on district heating. *Sustainable Energy Planning and Management*, 39-56.

Sandberg, E., Sneum, D. M., & Trømborg, E. (2018). Framework conditions for Nordic district heating - Similarities and differences, and why Norway sticks out. *Energy*, 105-119.

Schiff, A. (2008). The "Waterbed" Effect and Price Regulation. *Review of Network Economics*, 1-23.

Schilling, J., Naber, N., & Schepers, B. (2019). *Energiestrategie.* Delft: CE Delft.

Schilling, J., Nikdel, R., & De Boer, M. (2018). *Aansluiten op warmtenetten - Handreiking.* Delft: CE Delft.

Schmidt, D., Kallert, A., Blesl, M., Svendsen, S., Li, H., Nord, N., & Sipilä, K. (2017). Low Temperature District Heating for Future Energy Systems. *The 15th International Symposium on District Heating and Cooling* (pp. 26-38). Seoul, South Korea: Elsevier.

Schoots, K., Hekkenberg, M., & Hammingh, P. (2017). *Nationale Energieverkenning 2017.* Petten: Energieonderzoek Centrum Nederland.

Schwencke, A. M. (2019). *Lokale Energie Monitor 2019.* Utrecht: HIER Opgewekt.

Seawright, J., & Gerring, J. (2008). Case Selection Techniques in Case Study Research. *Political Research Quarterly*, 294-308.

Segers, R., Van den Oever, R., Niessink, R., & Menkveld, M. (2019). *Warmtemonitor 2017.* Den Haag: CBS & ECN.

Smoor, P.-P. (2017). *Warmtevisie.* Almere: Gemeente Almere.

Söderholm, P., & Wårell, L. (2011). Market opening and third party access in district heating networks. *Energy Policy*, 742-752.

Sørensen, P. A., & Schmidt, T. (2018). Design and Construction of Large Scale Heat Storages for District Heating in Denmark. *14th International Conference on Energy Storage* (pp. 1-15). Adana, Turkey: EnerSTOCK2018.

Späth, P. (2005). District heating and passive houses - Interfering strategies towards sustainable energy systems. *ECEEE Summer Study Proceedings* (s. 339-344). Stockholm: ECEEE.

Stadsverwarming Purmerend. (2017, February 23). *Onderhoud aan warmte-afleverset.* Retrieved from Stadsverwarming Purmerend: https://www.stadsverwarmingpurmerend.nl/wp-content/uploads/2017/02/informatieblad_onderhoud_met_opmaak.pdf

Stadsverwarming Purmerend. (2020). *Over Stadsverwarming Purmerend*. Retrieved from Stadsverwarming Purmerend: https://www.stadsverwarmingpurmerend.nl/over-stadsverwarming-purmerend/

Stadsverwarming Purmerend. (2020). *Standaard tarieven warmte per 1 juli* 2020.* Retrieved from Stadsverwarming Purmerend: https://www.stadsverwarmingpurmerend.nl/wp-content/uploads/2020/06/199.08-Tariefkaart_A4_standaard_Juli20_web.pdf

Statistics Denmark. (2020). *BOL201: Residents by county, use, tenure, ownership, year of construction, age and sex*. Retrieved from StatBank Denmark: https://www.statbank.dk/statbank5a/selectvarval/define.asp?PLanguage=1&subword=tabsel&MainTable=BOL201&PXSId=150335&tablestyle=&ST=SD&buttons=0

Statistics Denmark. (2020). *BY3: Population 1. January by urban, rural areas and population, area and population density*. Retrieved from StatBank Denmark: https://www.statbank.dk/statbank5a/SelectVarVal/Define.asp?MainTable=BY3&PLanguage=1&PXSId=0&wsid=cftree

Statistics Denmark. (2020). *BYGB40: Buildings and their heated area by region, unit, type of heating, use and year of construction*. Retrieved from StatBank Denmark: https://www.statbank.dk/statbank5a/SelectVarVal/Define.asp?Maintable=BYGB40&PLanguage=1

Statistics Denmark. (2020). *The average Dane*. Retrieved from Statistics Denmark: https://www.dst.dk/en/Statistik/Publikationer/gennemsnitsdanskeren#:~:text=Working%20life,of%20984%2C453%20DKK%20before%20tax.

Stichting Warmtenetwerk. (2019, October 4). *Zaanstad heeft de primeur met een open warmtenet*. Retrieved from Warmtenetwerk: https://warmtenetwerk.nl/nieuws/item/zaanstad-heeft-de-primeur-met-een-open-warmtenet/

Stockholm Exergi. (2019, November 19). Retrieved from Open District Heating: https://www.opendistrictheating.com/our-offering/

Surmeli Anac, A. N., Grözinger, J., van Tilburg, J., & Offerman, M. (2016). *Delivering the Energy Transition: What Role for District Energy.* Cologne: Ecofys.

Swelsen, W. (2019, July 4). Interview Ministerie van Economische Zaken en Klimaat. (S. Wiegerinck, Interviewer)

Tårnby Forsyning. (2020). *Organisation*. Retrieved from Tårnby Forsyning: http://www.taarnbyforsyning.dk/da-DK/Organisation.aspx

Ten Hoopen, J., & Hessels, J. (2003, September 15). *Voorstel van wet van de leden Ten Hoopen en Hessels tot het stellen van regels omtrent de levering van warmte aan kleinverbruikers (Warmtewet).* Retrieved from Officiële bekendmakingen: https://zoek.officielebekendmakingen.nl/kst-29048-1.html

The World Bank. (2018). *Urban population (% of total)*. Retrieved from The World Bank: https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?end=2017&start=1960&view=chart

Tieben, B., & Van Benthem, M. (2018). *Belang bij splitsing in de warmtemarkt.* Amsterdam: SEO Economisch Onderzoek.

Tigchelaar, C., Winters, E., Janssen, J. L., Huygen, A. E., & Brus, C. V. (2019). *Gemeentelijke besluitvorming warmtenetten. Lessen op basis van casussen.* Amsterdam: TNO.

Tredinnick, S. (2013, June 7). *Why Is District Energy Not More Prevalent in the U.S.?* Retrieved from HPAC Engineering: https://www.hpac.com/heating/why-district-energy-not-more-prevalent-us

UNEP. (2015). *District Energy in Cities.* Nairobi, Kenia: UNEP.

Van Dalen, J., & Van Beuningen, J. (2019, September 18). Interview Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. (S. Wiegerinck, Interviewer)

Van der Veek, F. (2019, September 26). Interview AFWC. (S. Wiegerinck, Interviewer)

Van Hest, R. (2020, May 12). *'Nieuwbouw aansluiten op heet warmtenet is zeer onverstandig'*. Retrieved from NOS: https://nos.nl/nieuwsuur/artikel/2333657-nieuwbouw-aansluiten-op-heet-warmtenet-is-zeer-onverstandig.html

Van Hest, R., & Van Laar, J. (2019, June 1). *Kritiek op aanleg warmtenet in Nijmegen 'is les voor andere gemeenten'.* Retrieved from NOS: https://nos.nl/nieuwsuur/artikel/2287218-kritiek-op-aanleg-warmtenet-in-nijmegen-is-les-voor-andere-gemeenten.html

Van Soerland, M. (2019, August 28). Interview HVC. (S. Wiegerinck, Interviewer)

Van Vliet, E., De Keijzer, J., Slingerland, E., Van Tilburg, J., Hofsteenge, W., & Haaksma, V. (2016). *Collectieve warmte naar lage temperatuur.* Utrecht: Ecofys.

Van Zanten, J. (2019, August 29). Interview AEB. (S. Wiegerinck, Interviewer)

Varmelast. (2020). *Daglige varmeplaner*. Retrieved from Varmelast: https://www.varmelast.dk/lastfordeling/varmeplaner

Varmelast. (2020). *The story - in brief*. Retrieved from Varmelast: https://www.varmelast.dk/om-varmelast/historien-kort

Varmelast. (2020). *What is load dispatching*. Retrieved from Varmelast: https://www.varmelast.dk/lastfordeling/hvad-er-lastfordeling

Vattenfall. (2019, December 11). *'Amsterdam South Connection' van Vattenfall.* Retrieved from Vattenfall: https://group.vattenfall.com/nl/siteassets/vattenfall-nl-site-assets/wat-we-doen/onze-activiteiten/stadswarmte/vf-420x210mm-asc-folder-251019voorbeeld-vouwen.pdf

Vattenfall. (2019, November 27). *Grootste zonnedak Amsterdam levert klimaatneutrale warmte aan woningen in Buiksloterham*. Retrieved from Vattenfall: https://group.vattenfall.com/nl/newsroom/actueel/persbericht/2019/grootste-zonnedak-amsterdam-levert-klimaatneutrale-warmte-aan-woningen-in-buiksloterham

Vattenfall. (2019, March 21). *Vattenfall aan de slag voor Amsterdamse warmte*. Retrieved from Vattenfall: https://group.vattenfall.com/nl/newsroom/actueel/persbericht/2019/vattenfall-aan-de-slag-voor-amsterdamse-warmte

Vattenfall. (2020). *Almere*. Retrieved from Vattenfall: https://www.vattenfall.nl/producten/stadsverwarming/co2-reductie/almere/

Vattenfall. (2020). *Amsterdam Noord en West*. Retrieved from Vattenfall: https://www.vattenfall.nl/producten/stadsverwarming/co2-reductie/Amsterdam-noord-en-west/

Vattenfall. (2020). *Amsterdam Zuid en Oost*. Hentet fra Vattenfall: https://www.vattenfall.nl/producten/stadsverwarming/co2-reductie/amsterdam-zuid-en-oost/

Vattenfall. (2020, June 25). *Biomassa: een weloverwogen tussenstap naar CO2-vrije stadsverwarming*. Retrieved from Vattenfall: https://www.vattenfall.nl/producten/stadsverwarming/biomassa/

Vattenfall. (2020). *E-boiler Diemen*. Hentet fra Vattenfall: https://group.vattenfall.com/nl/wat-we-doen/onze-activiteiten/stadswarmte/e-boiler-diemen

Vattenfall. (2020). *Stadsverwarming uit een thermoskan*. Retrieved from Vattenfall: https://orgaworld.nl/meer-over-ons-bedrijf/onze-locaties/amsterdam-greenmills

Vattenfall. (2020). *Tarieven voor stadsverwarming*. Retrieved from Vattenfall: https://www.vattenfall.nl/producten/stadsverwarming/tarieven-en-voorwaarden/

Vattenfall. (2020, June 25). *Vattenfall opnieuw met betrokkenen om tafel over biomassacentrale Diemen*. Retrieved from Vattenfall: https://group.vattenfall.com/nl/newsroom/actueel/persbericht/2020/vattenfall-opnieuw-met-betrokkenen-om-tafel-over-biomassacentrale-diemen

Vattenfall. (2020). *Warmtenet Nederland*. Retrieved from Vattenfall: https://www.vattenfall.nl/producten/stadsverwarming/warmtenet/#100713

Vattenfall NL. (2020). *Amsterdam South Connection*. Retrieved from Vattenfall: https://group.vattenfall.com/nl/wat-we-doen/onze-activiteiten/stadswarmte/asc

VEKS. (2019). *Køge Kraftvarmeværk*. Retrieved from VEKS: https://www.veks.dk/om-veks/fjernvarme-i-hovedstadsomraadet/kraftvarmevaerker/koege-kraftvarmevaerk

VEKS. (2020). *Annual Review 2019.* Albertslund: VEKS.

Verschuren, P., & Doorewaard, H. (2010). *Designing a Research Project.* The Hague: Eleven International Publishing.

Vestforbrænding. (2019). *Om os*. Retrieved from Vestforbrænding: https://www.vestfor.dk/om-os/

Vestforbrænding. (2020). *Ejerkreds*. Retrieved from Vestforbrænding: https://www.vestfor.dk/om-os/om-selskabet/ejerkreds/

Warmtenetwerk Zaanstad. (2020). *Biomassacentrale*. Retrieved from Warmtenetwerk Zaanstad: https://warmtenet.zaanstad.nl/biomassacentrale

Weiβ, J., Dunkelberg, E., & Hirschl, B. (2018). Implementing the Heating Sector Transition in Our Cities - Challenges and Problem-Solving Approached Based on the Example of Municipalities in Germany. In P. Droege, *Urban Energy Transition - Renewable Strategies for Cities and Regions* (pp. 283-292). Amsterdam: Elsevier.

Werling, J. T. (2019, June 4). Interview Ea Energianalyse. (S. Wiegerinck, Interviewer)

Werner, S. (2017). District heating and cooling in Sweden. *Energy*, 419-429.

Werner, S. (2017). International review of district heating and cooling. *Energy*, 617-631.

Wiebes, E. (2019). *Kamerbrief Warmtewet 2.0.* Den Haag: Ministerie van Economische Zaken en Klimaat.

Wiebes, E. (2020, June 22). *Start internetconsultatie Wet Collectieve Warmtevoorziening (Warmtewet 2).* Retrieved from Rijksoverheid: https://www.rijksoverheid.nl/documenten/kamerstukken/2020/06/22/kamerbrief-start-internetconsultatie-wet-collectieve-warmtevoorziening

Wiebes, E. (2020). *Start internetconsultatie Wet Collectieve Warmtevoorziening [Kamerbrief].* Den Haag: Ministerie van Economische Zaken en Klimaat.

Wissner, M. (2014). Regulation of district-heating systems. *Utilities Policy*, 63-73.

Yin, R. K. (2003). *Case study research: design and methods.* Thousand Oaks: Sage Publications, Inc.

Zeman, J., & Werner, S. (2004). *District Heating Systems Ownership Guide.* Watford: BRE.

Appendices

A. Consumer categories for different countries and regions

Figure 51, below, provides an overview of the annual heat delivery through DH systems in 2014 for the four main categories of consumers in several countries and regions in the world. Noticeable are the large differences between the DH sectors in the European Union, Russia and China on one hand and the rest of the world on the other hand.

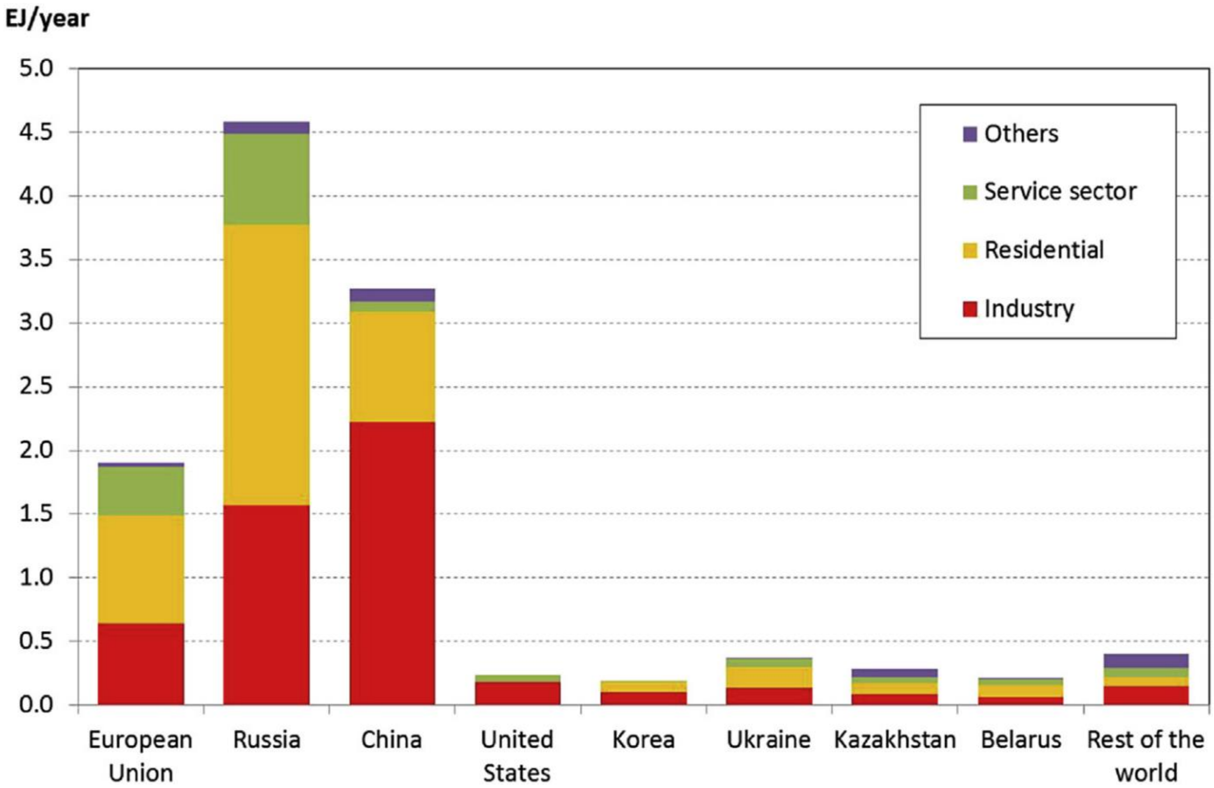


Figure 51 – Annual heat delivery through DH systems per consumer category for different countries and regions in 2014 (Werner, 2017, pp. 619-620)

B. Main concepts of seasonal thermal energy storage

The four most important concepts of thermal energy storage are schematically represented in the figure below.

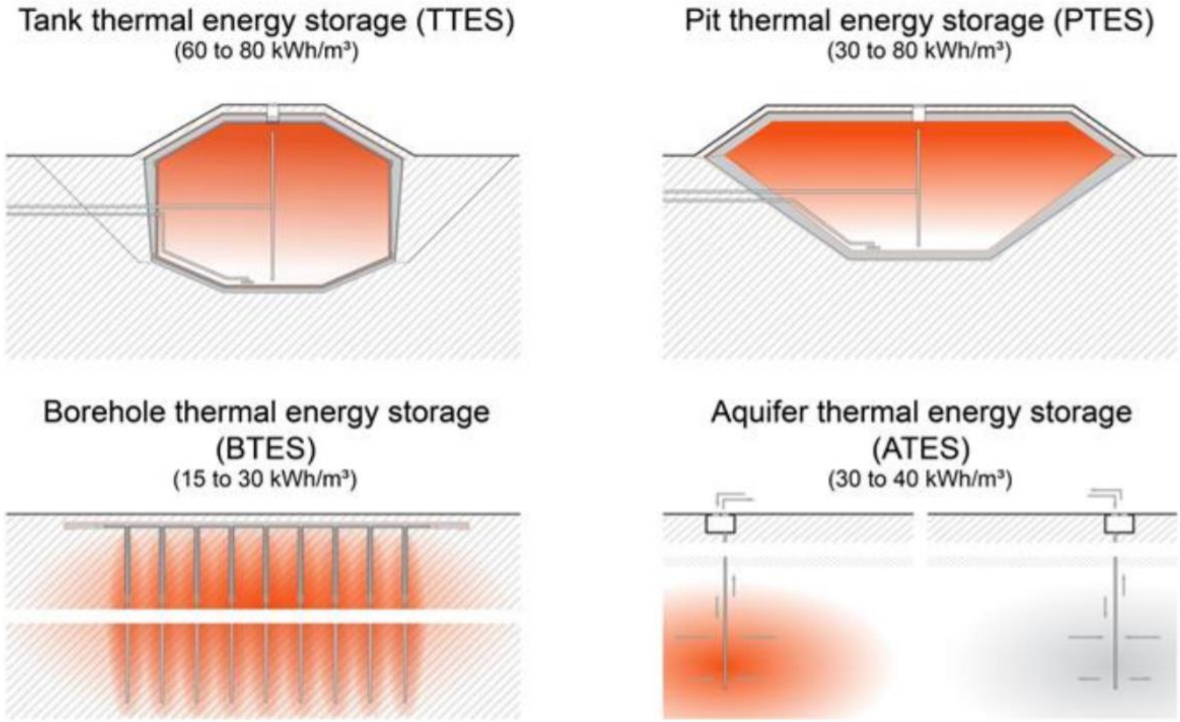


Figure 52 – The main concepts of seasonal thermal energy storage: TTES, PTES, BTES & ATES (Sørensen & Schmidt, 2018)

C. Format for introductory email

In order to introduce the research and its case studies to potential interview candidates and to ask them to participate in an interview, a standard format for an introduction is drafted, to be sent via email. There are four versions of this standard format: one for stakeholder interviews and one for expert interviews and each of these in both English (for Denmark) and Dutch (for the Netherlands). During and after conducting the interviews the direction and questions of this study have been modified to better fit the problem statement and scope of the research. These introductory formats date from the earliest interviews and might not be up to date or fully represent the course of the research any more. The messages that were sent have also been customised to better address the specific interview candidate.

a. Introduction to experts (English)

Dear <name>,

Currently I am conducting research on the planning process of district heating systems, as part of my graduate thesis at Delft University of Technology. I am executing this research as a research intern at Alliander, although the research is independent from company interests. Alliander is the largest of the three publicly owned distribution system operators (DSO) for both gas and electricity in the Netherlands, with over 5.5 million connections.

I am also collaborating with (a PhD-candidate at) the Technical University of Denmark (DTU) in Copenhagen. For my research I will study both Amsterdam and Copenhagen as cases and in both cities I will interview stakeholders within district heating systems. Examples of these stakeholders are municipalities, energy companies, housing associations, DSO's/TSO's, cooperatives, regulators and consultancy companies. I will stay in Copenhagen for about 3 weeks, from May 20th to June 6th.

At the moment I am working on the identification and definition of factors that influence district heating system functioning. I am also studying the potential for 'open' district heating systems. Factors like third-party access, unbundling, ownership and others could be of influence. In scientific literature and research reports there seems to be no consensus about what an 'open' district heating system is and what not. Therefore the feasibility, desirability and appropriate design of certain types of district heating systems are evaluated based on arguments that consider different concepts, with different characteristics. I want, as part of this research, establish a framework to clearly define and categorise district heating systems and, by doing so, contribute to a better founded debate.

In order to do this I would like to interview you as an expert in the field of district heating and as an independent party within the sector, without an individual interest in production, distribution or delivery of thermal energy. In the interview, I would like to focus on the definition of ('open') district heating systems, on the characteristics of the Copenhagen district heating sector and on the current planning process. Besides you, I will also interview some other experts and several stakeholders within the Copenhagen heating sector. Together, these interviews support building an overview of the Copenhagen district heating sector, the types of district heating systems and the planning processes.

The recording and transcript of the interview will not be published and participants will be anonymised if desired. I hope you agree on participating in this interview. We can plan a date and time for the interview via email or telephone. You could also contact me via email or telephone if you have further questions regarding the research or the interview. My contact details can be found below.

I hope to hear from you.

Kind regards,

Stijn Wiegerinck

b. Introductie voor experts (Dutch)

Beste <naam>,

Momenteel doe ik onderzoek naar het ontwerp en planning- & ontwerpproces van warmtenetten voor mijn afstudeerscriptie bij de TU Delft. Dit onderzoek doe ik als afstudeerstagiair bij Alliander, hoewel het onderzoek zelf volledig onafhankelijk is. Ook werk ik voor dit onderzoek samen met (een PhD'er van) de Technical University of Denmark (DTU) in Kopenhagen, waar ik in mei en juni ook drie weken ben geweest om interviews af te nemen bij 11 verschillende partijen binnen het warmtenet van Greater Copenhagen.

Ik werk onder andere aan het beschrijven van factoren in het functioneren van warmtenetten. Ook onderzoek ik de mogelijkheden voor 'open' warmtenetten. Zaken als TPA, splitsing, publiek/privaat eigenaarschap en andere factoren kunnen hierin van invloed zijn. In de wetenschappelijke literatuur en in allerlei onderzoeksrapporten lijkt geen consensus te zijn over wat een 'open' warmtenet precies is (en vooral: wat niet). Hierdoor wordt de haalbaarheid, wenselijkheid of gewenste vorm van bepaalde ontwerptypen van warmtenetten beoordeeld op basis van argumentatie die uitgaat van verschillende concepten, met verschillende eigenschappen. Ik wil, als onderdeel van mijn onderzoek, een framework opstellen om warmtenetten duidelijk te definiëren en zo bijdragen aan een beter onderbouwde discussie.

Onder andere hierover wil ik u graag interviewen als expert op dit gebied en als onafhankelijke partij in deze discussie, zonder belang in de productie, levering of distributie van warmte. In dit interview wil ik graag focussen op de definitie van het concept (open) warmtenet, op de kenmerken van de Nederlandse warmtesector en op het huidige planning- en ontwerpproces van warmtenetten. Naast u en nog enkele andere experts zal ik ook een aantal stakeholders in Nederlandse warmtenetten interviewen, met een focus op de regio Amsterdam. Samen moet dit een goed beeld opleveren van de Nederlandse warmtesector, de typen warmtenetten en het planning- en ontwerpproces.

De opname en transcriptie van dit interview zullen niet worden gepubliceerd en indien gewenst zullen participanten worden geanonimiseerd. Ik hoop dat u bereid bent aan dit interview deel te nemen. Voor het plannen van een interview kan ik ook telefonisch contact met u opnemen. Voor andere vragen over het onderzoek en dit interview kunt u mij mailen of bellen via onderstaande gegevens.

Alvast bedankt voor uw tijd en medewerking.

Met vriendelijke groet,

Stijn Wiegerinck

c. Introduction to stakeholders (English)

Dear <name>,

Currently I am conducting research on the planning process of district heating systems, as part of my graduate thesis at Delft University of Technology. I am executing this research as a research intern at Alliander, although the research is independent from company interests. Alliander is the largest of the three publicly owned distribution system operators (DSO) for both gas and electricity in the Netherlands, with over 5.5 million connections.

I am also collaborating with (a PhD-candidate at) the Technical University of Denmark (DTU) in Copenhagen. For my research I will study both Amsterdam and Copenhagen as cases and in both cities I will interview stakeholders within district heating systems. Examples of these stakeholders are municipalities, energy companies, housing associations, DSO's/TSO's, cooperatives, regulators and consultancy companies. I will stay in Copenhagen for about 3 weeks, from May 20th to June 6th.

The interviews will focus on three matters:

- *What factors influence the functioning of a district heating system?*
- *How can the district heating system contribute to a sustainable, affordable and reliable heat provision?*
- *What are the characteristics of the various stakeholders within district heating systems, which roles do they fulfil and what are their interests and requirements towards the system?*
- *How are district heating systems currently planned, designed and developed and what are the greatest challenges?*

Furthermore, there is an ongoing debate in the Netherlands about the role of district heating systems. Often, there is a lack of support for district heating systems and sometimes more 'open' district heating systems are perceived as not feasible or even not desirable. There also is uncertainty about what party should assume a leading or coordinating role, how district heating systems need to be organised and regulated and what exactly we call 'open' and what not. Using the information that I gather in these interviews, I want to answer the questions above. Also, I want to make recommendations on how the planning process of district heating systems can support all stakeholders in their transition towards sustainable heating.

Given your position at <company> and the role <company> fulfils in the heating sector, I would like to interview you and discuss the topics mentioned above. The role of <company> is very relevant to get a good impression of the heating *sector in Copenhagen and I think your experiences and that of <company> could be very useful to my research. Therefore I hope that your are willing to participate in an interview.*

The recording and transcript of the interview will not be published and participants will be anonymised if desired. I hope you agree on participating in this interview. We can plan a date and time for the interview via email or telephone. You could also contact me via email or telephone if you have further questions regarding the research or the interview. My contact details can be found below.

I hope to hear from you.

Kind regards,

Stijn Wiegerinck

d. Introduction voor stakeholders (Dutch)

Beste <naam>,

Momenteel doe ik onderzoek naar het ontwerp en planning- & ontwerpproces van warmtenetten voor mijn afstudeerscriptie bij de TU Delft. Dit onderzoek doe ik als afstudeerstagiair bij Alliander, hoewel het onderzoek zelf volledig onafhankelijk is. Ook werk ik voor dit onderzoek samen met (een PhD'er van) de Technical University of Denmark (DTU) in Kopenhagen, waar ik in mei en juni ook drie weken ben geweest om interviews af te nemen bij 11 verschillende partijen binnen het warmtenet van Greater Copenhagen.

Voor een deel van mijn onderzoek neem ik interviews af bij verschillende partijen die actief zijn binnen warmtenetten. Denk hierbij aan gemeenten, woningcorporaties, energiebedrijven, netbeheerders, bewonerscollectieven en -coöperaties en adviesbureaus. Ik focus in deze interviews op drie zaken:

- *Welke factoren beïnvloeden het functioneren van een warmtenet?*
- *Hoe kan het warmtenet bijdragen aan duurzame, betaalbare en betrouwbare warmtevoorziening?*
- *Wat zijn de kenmerken van de verschillende stakeholders binnen warmtenetten, welke rollen vervullen zij en wat zijn hun wensen en eisen aan het warmtenet?*
- *Hoe worden warmtenetten momenteel ontworpen en ontwikkeld en wat zijn daarin de grootste uitdagingen?*

Momenteel ontbreekt het nog wel eens aan draagvlak voor warmtenetten en worden meer 'open' warmtenetten vaak niet haalbaar of zelfs niet wenselijk geacht. Ook is er discussie over welke partij een leidende rol moet nemen, hoe warmtenetten moeten worden geordend en/of gereguleerd en wat men nou precies een 'open' warmtenet noemt en wat niet. Met de informatie die ik in de interviews vergaar wil ik deze vragen beantwoorden. Daarnaast wil ik aanbevelingen doen hoe het plannings- en ontwerpproces van warmtenetten kan bijdragen aan de warmtetransitie van alle stakeholders.

Gezien uw functie binnen <organisatie> en de rol die <organisatie> vervult binnen de warmtesector zou ik u graag interviewen en bovenstaande onderwerpen bespreken. De rol van <organisatie> is erg relevant voor een goed beeld van de warmtesector en uw ervaring en die van <organisatie> zijn zeer nuttig voor mijn onderzoek. Ik hoop dan ook dat u bereid bent aan dit interview deel te nemen.

De opname en transcriptie van dit interview zullen niet worden gepubliceerd en indien gewenst zullen participanten worden geanonimiseerd. Ik hoop dat u bereid bent aan dit interview deel te nemen. Voor het plannen van een interview kan ik ook telefonisch contact met u opnemen. Voor andere vragen over het onderzoek en dit interview kunt u mij mailen of bellen via onderstaande gegevens.

Alvast bedankt voor uw tijd en medewerking.

Met vriendelijke groet,

Stijn Wiegerinck

D. Interview guide

Like the introductory email formats to stakeholders and experts, the interview guides are also somewhat outdated. They have been modified only slightly, mainly to better match the questions and priorities for the interview to the stakeholder or expert in question. However, the interview guide has not been updated too much, as the comparability and representativeness of the interviews then might be lower. As is appropriate for semi-structured interviews, the conversations with interviewees do not rigorously follow this interview guide and especially not the sequence of subjects and questions. The guide is mainly used to support the interviewer and ensure all relevant questions can be asked. During interviews held earlier, the interview guide was used more extensively than during later interviews.

a. Stakeholder interview guide (English)

Checklist before interview

- Send email containing basic information about the research. Agree on date, time and location for the interview and secure 1 to 1.5 hours of the interviewee's time.
- Make sure mobile phone battery is sufficiently charged for (audio) recording the whole interview. Ask permission for recording the interview (again).
- Print this interview format on paper.

Instruction for interviewer

- Communicate clearly, but do not talk too much yourself.
- Be flexible towards the interviewee in terms of topics and details that are discussed, but stick with the interview structure, at least roughly.
- Ask questions if answers are not clear or incoherent. Be critical, but do not be too bold or direct.

Introduction (5 minutes)

Research

This interview is part of my graduate thesis research at Delft University of Technology in the Netherlands. The research focuses on open district heating systems (ODHS):

- The definition of this concept
- The potential benefits of ODHS
- The characteristics of the stakeholders in (O)DHS
- Their requirements towards the system
- The (current) planning process of (O)DHS

The research is conducted in collaboration with Delft University of Technology (TU Delft) , the Dutch (publicly owned) DSO for electricity and gas Alliander and the Technical University of Denmark (DTU). I would like to interview you because of your position within your company/institution and its role within the district heating sector.

Practical matters

- The interview will take approximately 1 to 1.5 hours.
- All data from the interviews will be treated carefully and only included anonymously in the research report.
- It is strongly preferred to record the interview in order to transcribe the interview afterwards, make notes and be able to validate the findings. After transcription of the interview, the recording will be deleted. Will you give permission to record the interview?
- A transcript of the interview will be provided to you. If would be very helpful if you could validate the transcription.
- The information from the interview will be used in a descriptive way, in a case study on the Amsterdam/Copenhagen district heating sector. Stakeholder types will be described, not individual stakeholders/companies.

Content

The interview will consist of four parts:

1. The definition of open district heating systems
2. Characteristics of your organisation and its role in the district heating sector
3. The current development and planning process for district heating systems and the challenges that are encountered
4. Requirements of your organisation towards an open district heating system

Your experience and expertise are very valuable to this research. There are no right or wrong statements and what you say will be treated carefully.

Phase 1 – Stakeholder analysis (15 minutes)

The first part of the interview will delve into the particular stakeholder that is interviewed. What kind of organisation is this and how does it relate to peers? The aim of this part of the research is to be able to describe the stakeholder type and the role this stakeholder fulfils, not to describe the particular institution that is interviewed. For example: to describe the stakeholder type of the housing corporation and the role as consumer it fulfils.

It is possible to discuss documentation that is found online or that is provided in advance by the organisation that is interviewed. Receiving documentation following the interview is also welcomed, as this can further clarify remaining questions or be supplemental to the answer provided by the interviewee.

QUESTION	OBJECTIVE
1. Can you tell something about your organisation and your role in it? a. What is the organisation size? i. Employees ii. Working area iii. Revenue b. Is the organisation public or private? c. Can you give a brief overview of the organisational history? d. What are the products/services the organisation provides?	*Description of stakeholder characteristics.* Subject: General characteristics
2. What are the activities of your organisation within the district heating sector?	*Description of stakeholder characteristics.* Subject: Activities
3. Are there other organisations that are similar to yours/with whom you work together? a. Within your market/outside your market? b. Are these organisations competitors?	*Description of stakeholder characteristics.* Subject: Peers in market
4. What are the main objectives of your organisation within the district heating sector? a. How are these objectives pursued and are they achieved? b. What interferes with these objectives?	*Description of stakeholder objectives.* Subject: Drivers and barriers for achievement of stakeholder objectives
5. What would be the optimal way for your organisation to design and organise DHS? a. To achieve organisational goals?	*Description of stakeholder objectives.* Subject: DHS design
6. What is the business model of your organisation in the district heating sector?	*Stakeholder business model.* Subject: Business model

Phase 2 – Review of ODHS concept (10 minutes)

This phase will go into the concept of Open District Heating Systems (ODHS) and explore what the view of the interviewee and of his/her organisation is on the topic. Some questions will just ask for thoughts, interpretation and descriptions, others will ask more specifically about the influence of factors of the system on the design and functioning of an (O)DHS or about the influence of the ODHS design on public values like sustainability.

The objective of this part is to generate input for a definition framework for ODHS.

QUESTION	OBJECTIVE
1. How would you describe an **open** district heating system? Why would you call this an open system?	*Definition of the concept of ODHS.* Subject: Concept of ODHS
2. What are the main factors that determine if a system is open or not? a. Influence of TPA? b. Influence of unbundling of grid management? c. Influence of public/private ownership?	*Definition of the concept of ODHS.* Subject: Factors influencing "openness"

3. What is the role distribution in your definition of ODHS? a. Producer, TSO, DSO, SSA, provider, consumer? b. Is it possible to have one integrated party in the (O)DHS, possibly in combination with TPA?	*Definition of the concept of ODHS.* Subject: Role distribution
4. How would your definition of an ODHS influence the 1. sustainability 2. affordability 3. reliability of the heat provision?	*Definition of the concept of ODHS.* Subject: Impact of ODHS on public interests
5. Do you think a DHS with TPA for both producers and providers is possible? a. Is this possible in Denmark/Copenhagen? b. What needs to be organised or changed in order to achieve this?	*Feasibility assessment of ODHS.* Subject: Double TPA in DHS
6. What do you think is the optimal way of organising district heating systems, from a societal perspective (optimal for achievement of public values)?	*Feasibility assessment of ODHS.* Subject: Ideal design of DHS
7. Do you know any examples of (operational) ODHS and if yes, how are they realised and should this serve as an example for other areas?	*Feasibility assessment of ODHS.* Subject: Examples of ODHS

Phase 3 – Review of (O)DHS planning process (20 minutes)

In the third phase the interviewee is asked to discuss and review the current planning process of (open) district heating systems, the role of his/her organisation in this process, the influence it can exercise, the business case of different phases of the planning process and some specific topics like (physical) quality requirements.

The goal is to describe the current planning process and identify challenges the current process poses, in general and for the design and development of open DHS.

QUESTION	OBJECTIVE
1. What is the role of your organisation in the planning process of (O)DHS? a. If not involved: what could be the role of your organisation?	*Planning process description.* Subject: Role of stakeholders
2. How much influence do you think your organisation has on the (O)DHS design? a. Do you think this is enough? b. What would you do different in the planning process if your organisation had more influence?	*Planning process description.* Subject: Influence of stakeholders
3. How are existing buildings connected to the DHS? a. What way were these buildings heated before the DHS? b. Was the connection of existing buildings voluntary or mandatory? c. Which party was responsible for the costs of the connection?	*Existing building stock.* Subject: Connection to DHS
4. What does the business case look like? a. Are new consumers expected to contribute to investment costs of the network? i. E.g. in the form of a "connection fee"? b. Which/how many parties are investing in the construction of new DH networks? c. What parties create an income from (daily) operation? What parties make a profit? d. Are these the same parties as parties that invest in construction of the system? e. What parties do maintenance of the DHS? f. Are these the same parties as the operating parties?	*Financials DHS (design, construction, operation & maintenance.* Subject: Investment case
5. What factors influence the technical design of the DHS?	*Technical design.*

a. What factors would be relevant for ODHS, compared to 'regular' DHS?	Subject: Design factors
6. Are there (physical) quality requirements towards producers of thermal energy? a. Regarding temperature, pressure, water quality, acidity, etc.?	*Technical design.* Subject: Quality requirements producers
7. What are the pros and cons of the current planning process, in the eyes of your organisation? a. Pros and cons for society? b. Pros and cons for your organisation/busin. mod.?	*Planning process review.* Subject: Pros and cons
8. Do you think there would be differences if the systems would be built from scratch in 2019? a. In the planning process? b. In the actual design itself?	*Planning process review.* Subject: "Retake" of DHS design

Phase 4 – Requirements analysis (20 minutes)

In the final part of the interview the interviewee is asked to describe and reflect on the requirements his/her organisation has towards the district heating system. How is the relation between requirements of different stakeholders, how are these taken into account by others and how are these addressed in the planning process? Are there improvements needed in the requirements elicitation and planning process and if yes, what should these improved processes look like?

QUESTION	OBJECTIVE
1. What requirements does your organisation have towards the DHS? What is important to your organisation?	*Organisational requirements description.* Subject: Description
2. Does your organisation have an idea of other stakeholders' requirements? a. Are these taken into account? How?	*Organisational requirements description.* Subject: Other stakeholders
3. How do your requirements relate to other stakeholders' requirements? a. How well are these requirements aligned to public values like sustainability, affordability and reliability? b. How well are your requirements accepted by other stakeholders?	*Organisational requirements description.* Subject: Alignment and acceptation
4. Are your requirements addressed in the current planning process of DHS? To what extent? a. What is the organisation's influence on addressing these requirements?	*Organisational requirements description.* Subject: Addressing of requirements
5. What organisation is responsible for addressing stakeholder requirements within the heat planning process? a. Is this only one party? Is this party also owner of the system/infrastructure? b. Is this a public or private organisation?	*Planning process description.* Subject: Addressing of requirements
6. In what way do you think the planning process should be organised? a. Who should be responsible for addressing the stakeholders' requirements? b. How should stakeholders be included in the planning process?	*Planning process description.* Subject: Process organisation, stakeholder requirements
7. Is there a need for improvement of the requirements elicitation process and the planning process of DHS in Copenhagen? a. I.e.: the way stakeholder requirements are translated into system requirements? b. The way these requirements are translated into a system design?	*Identification of improvements.* Subject: Requirement elicitation, constitution of system requirements and conceptual (system) design

Stakeholders-specific questions and general Copenhagen case information (10 minutes)

These questions can be discussed with individual stakeholders, if necessary and possible. These are not questions that can be and/or need to be discussed with every interviewee. If time is left after the 4 interview parts, time can be filled with the questions below.

QUESTION	OBJECTIVE
1. How is the price determined that your organisation pays/receives for receiving/delivering thermal energy (in €/DKK per GJ?	*System financials.* Subject: Pricing of thermal energy
2. What is the price (individual/residential) consumers in Copenhagen pay per GJ? a. Is this a fixed price for all consumers in the system, or is the price variable per district? b. Is there a possibility to sign a contract for heat delivery for a certain price, e.g. for industrial consumers?	*System financials.* Subject: Pricing of thermal energy
3. What % of the income of an average household is spent on heating? a. When using district heating? b. When using an alternative heat source?	*System financials.* Subject: Heating expenses as % of income
4. What kind of taxes are there on the heat that is delivered through DHS? a. Who pays these taxes? b. How high are these taxes?	*System financials.* Subject: Taxation
5. What kind of subsidies are available within the DH sector? a. For production? b. For grid management? c. For delivery? d. For purchase?	*System financials.* Subject: Subsidies
6. What alternatives for DH are available for consumers in Copenhagen? a. Residential consumers? i. Rental sector ii. Home owners b. Commercial consumers? c. Industrial consumers?	*Other energy systems.* Subject: Alternatives for DH

Finalisation of the interview (5 minutes)

Indicate the (main part of) the interview is over and thank the interviewee for his/her time. Briefly discuss the following issues:

- Are there any remaining questions or final comments from your side?
- Have there been any questions that you found strange, you did not expect or that you want to revise your answer for/you have changed your mind on?
- Is it ok if I contact you with additional questions after the interview?
- Could you validate the (summary of) the transcript of this interview? I will send you this via email, if that is ok.
- Do you want to receive (a summary of) the thesis after completion of the research?

Finalisation for the interviewer

Directly after the interview (at least on the same day) make notes on the following questions:

- How did the interview go?
- Has the interview provided you with new insights or information?
- How was the interview setting (formal, relaxed, confusing, clear, time shortage)?

b. Expert interview guide (English)

Checklist before interview

- Send email containing basic information about the research. Agree on date, time and location for the interview and secure 1 to 1.5 hours of the interviewee's time.
- Make sure mobile phone battery is sufficiently charged for (audio) recording the whole interview. Ask permission for recording the interview (again).
- Print this interview format on paper.

Instruction for interviewer

- Communicate clearly, but do not talk too much yourself.
- Be flexible towards the interviewee in terms of topics and details that are discussed, but stick with the interview structure, at least roughly.
- Ask questions if answers are not clear or incoherent. Be critical, but do not be too bold or direct.

Introduction (5 minutes)

Research

This interview is part of my graduate thesis research at Delft University of Technology in the Netherlands. The research focuses on open district heating systems (ODHS):

- The definition of this concept
- The potential benefits of ODHS
- The characteristics of the stakeholders in (O)DHS
- Their requirements towards the system
- The (current) planning process for (O)DHS

The research is conducted in collaboration with Delft University of Technology (TU Delft) , the Dutch (publicly owned) DSO for electricity and gas Alliander and the Technical University of Denmark (DTU). I would like to interview you because of your position within your company/institution and its role within the district heating sector.

Practical matters

- The interview will take approximately 1 to 1.5 hours.
- All data from the interviews will be treated carefully and only included anonymously in the research report.
- It is strongly preferred to record the interview in order to transcribe the interview afterwards, make notes and be able to validate the findings. After transcription of the interview, the recording will be deleted. Will you give permission to record the interview?
- A transcript of the interview will be provided to you. If would be very helpful if you could validate the transcription.
- The information from the interview will be used in a descriptive way, in a case study on the Amsterdam/Copenhagen district heating sector. Stakeholder types will be described, not individual stakeholders/companies.

Content

The interview will consist of three parts:

1. The definition of open district heating systems
2. Possible advantages of and challenges for open district heating systems
3. The current development and planning process for district heating systems and the challenges that are encountered

Your experience and expertise are very valuable to this research. There are no right or wrong statements and what you say will be treated carefully.

Phase 1 – Review of ODHS concept

This phase will go into the concept of Open District Heating Systems (ODHS) and explore what the view of the interviewee and of his/her organisation is on the topic. Some questions will just ask for thoughts, interpretation and descriptions, others will ask more specifically about the influence of factors of the system on the design and functioning of an (O)DHS or about the influence of the ODHS design on public values like sustainability.

The objective of this part is to generate input for a definition framework for ODHS.

QUESTION	OBJECTIVE
1. How would you describe an **<u>open</u>** district heating system? Why would you call this an open system?	*Definition of the concept of ODHS.* Subject: Concept of ODHS
2. What are the main factors that determine if a system is open or not? a. Influence of TPA? b. Influence of unbundling of grid management? c. Influence of public/private ownership?	*Definition of the concept of ODHS.* Subject: Factors influencing “openness”
3. What is the role distribution in your definition of ODHS? a. Producer, TSO, DSO, SSA, provider, consumer? b. Is it possible to have one integrated party in the (O)DHS, possibly in combination with TPA?	*Definition of the concept of ODHS.* Subject: Role distribution
4. How would your definition of an ODHS influence the 1. sustainability 2. affordability 3. reliability of the heat provision?	*Definition of the concept of ODHS.* Subject: Impact of ODHS on public interests
5. Is it possible to have different versions of (O)DHS, with varying degrees of openness?	*Definition of the concept of ODHS.* Subject: Degree of openness
6. Do you think a DHS with **TPA for both** producers and providers is possible? Why/why not? a. Is this possible in Denmark/Copenhagen? b. What needs to be organised or changed in order to achieve this?	*Feasibility assessment of ODHS.* Subject: Double TPA in DHS
7. What do you think is the optimal way of organising district heating systems, from a societal perspective (optimal for achievement of public values)?	*Feasibility assessment of ODHS.* Subject: Ideal design of DHS
8. Do you know any examples of (operational) ODHS? a. If yes, do you think these should serve as an example to other areas? b. How are these examples realised?	*Feasibility assessment of ODHS.* Subject: Examples of ODHS
9. Could you quickly describe/draw/outline a simple framework that is able to define the concept of ODHS and categorise DHS in different types (open/not open)?	*Definition of the concept of ODHS.* Subject: Definition framework
10. When you look at this simple framework, what are your questions and what would be your feedback? a. Differences in TPA-types (voluntarily, etc.); is this a clear and necessary difference? b. Producers/providers only; is this realistic? c. Is (un-) bundling a relevant factor for the definition of **open** DHS? d. Where would you place the Greater Copenhagen district heating system?	*Definition of the concept of ODHS.* Subject: Review of conceptual definition framework

Phase 2 – Pros and cons of ODHS

QUESTION	OBJECTIVE
1. What could be potential benefits of ODHS, compared to ‘regular’ DHS (using the definition given by interviewee)? a. Benefits for society? b. Benefits for only a few stakeholders? c. Benefits for consumers?	*Assessing impact of ODHS.* Subject: Potential benefits
2. What could be potential disadvantages of ODHS, compared to ‘regular’ DHS (using the definition given by interviewee)?	*Assessing impact of ODHS.* Subject: Potential disadvantages
3. What are challenges for realising these ODHS?	*Indicating barriers.* Subject: Challenges in realisation
4. What are challenges in operating these ODHS?	*Indicating barriers.* Subject: Challenges in operation

Finalisation of interview

Indicate the (main part of) the interview is over and thank the interviewee for his/her time. Briefly discuss the following issues:

- Are there any remaining questions or final comments from your side?
- Have there been any questions that you found strange, you did not expect or that you want to revise your answer for/you have changed your mind on?
- Is it ok if I contact you with additional questions after the interview?
- Could you validate the (summary of) the transcript of this interview? I will send you this via email, if that is ok? Do you want to receive (a summary of) the thesis after completion of the research?

Finalisation for interviewer

Make notes on:

- How did the interview go?
- Has the interview provided you with new insights or information?
- How was the interview setting (formal, relaxed, confusing, clear, time shortage)?

E. Additional analyses for case reports

a. Relative population size of 17 municipalities in GC area

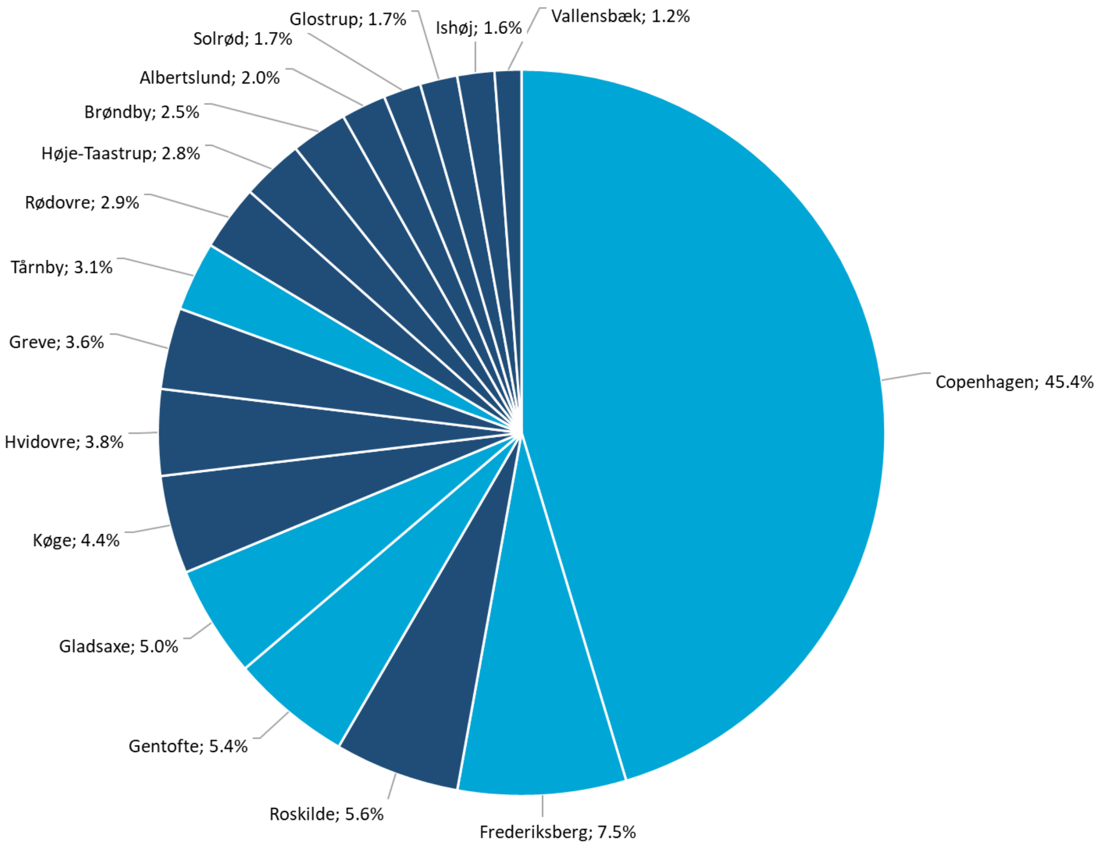


Figure 53 – Municipalities in CTR and VEKS district heating area; share of population in total GC area (own illustration)

b. Summary Greater Copenhagen DH system

Municipality	Population		Population density	Local DH distribution company	Heating technologie	Buildings on DH	
	#	*%*	*#/km²*	*Ownership*	*DH market share*	*Residential*	*Non-residential*
Copenhagen	632,340	45.4%	8,232	Municipal	96.1%	64.2%	35.8%
Frederiksberg	104,305	7.5%	11,979	Municipal	96.5%	78.6%	21.4%
Roskilde	77,462	5.6%	2,418	Municipal/cooperative	59.1%	58.3%	41.7%
Gentofte	74,830	5.4%	3,129	Municipal	59.6%	69.4%	30.6%
Gladsaxe	69,262	5.0%	3,199	Municipal	46.1%	59.4%	40.6%
Køge	60,979	4.4%	2,033	Municipal	13.4%	55.9%	44.1%
Hvidovre	53,527	3.8%	2,862	Cooperative	56.7%	50.8%	49.2%
Greve	50,558	3.6%	1,977	Municipal	28.7%	66.7%	33.3%
Tårnby	42,989	3.1%	3,119	Municipal	43.0%	47.4%	52.6%
Rødovre	40,652	2.9%	3,630	Municipal	52.9%	63.7%	36.3%
Høje-Taastrup	38,494	2.8%	2,567	Cooperative	70.8%	53.6%	46.4%
Brøndby	35,090	2.5%	2,659	Cooperative	76.9%	53.3%	46.7%
Albertslund	27,731	2.0%	2,667	Municipal	91.1%	48.8%	51.2%
Solrød	23,255	1.7%	2,578	Cooperative	39.2%	80.1%	19.9%
Glostrup	23,128	1.7%	2,704	Municipal	56.7%	41.3%	58.7%
Ishøj	22,989	1.6%	3,795	Municipal	52.0%	70.5%	29.5%
Vallensbæk	16,633	1.2%	3,939	Municipal	59.4%	68.0%	32.0%
Total CTR area	923,726	66.3%	7,626	Municipal	86.6%	65.6%	34.4%
Total VEKS area	470,498	33.7%	2,664	Municipal/cooperative	53.7%	56.2%	43.8%
Total GC area	1,394,224	100%	5,952	Municipal/cooperative	74.3%	63.1%	36.9%

Table 14 – Summary of GC DH system, showing population, density, DH-company ownership, DH market share and building use for all 17 municipalities

c. DH per building type, building use and share of heating technologies for municipalities in CTR area

Municipality of Copenhagen

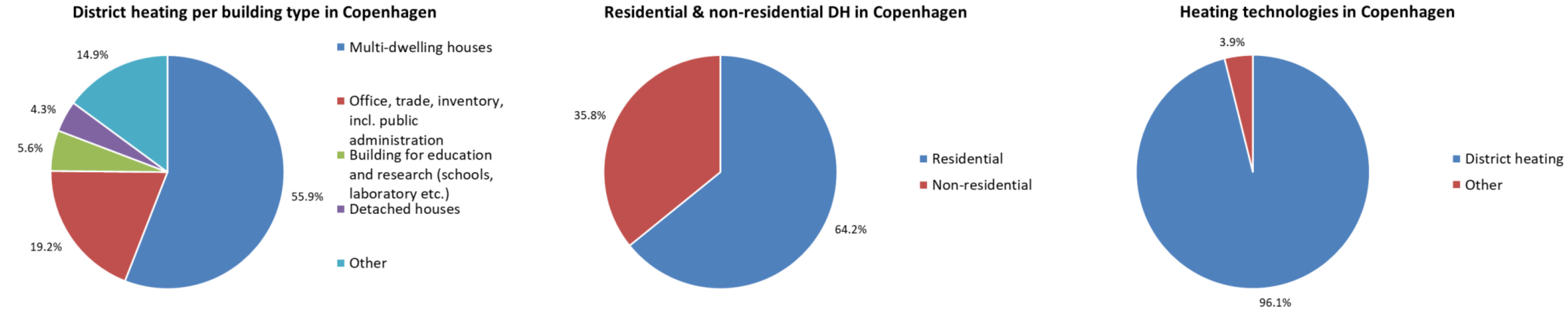


Figure 54 – DH per building type, building use of DH floor area and DH market share in municipality of Copenhagen

Municipality of Frederiksberg

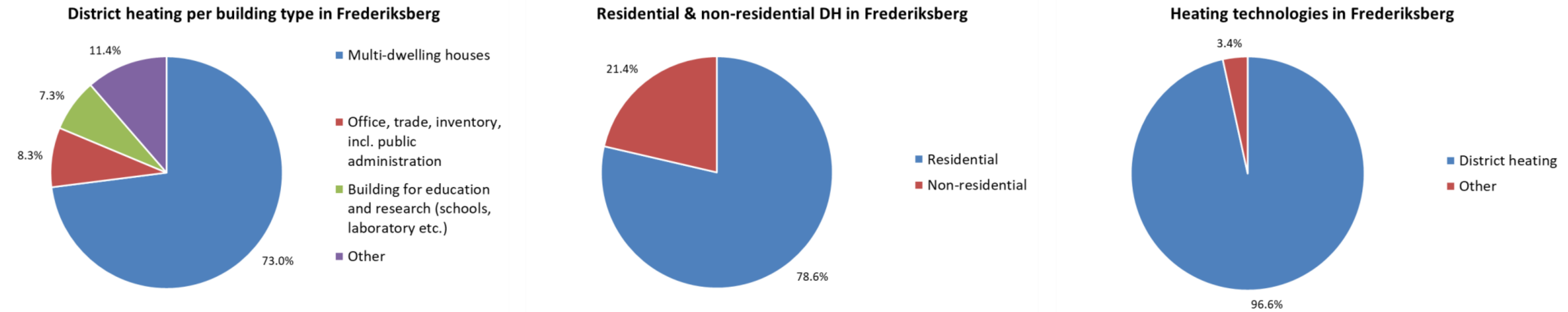


Figure 55 – DH per building type, building use of DH floor area and DH market share in municipality of Frederiksberg

Municipality of Gentofte

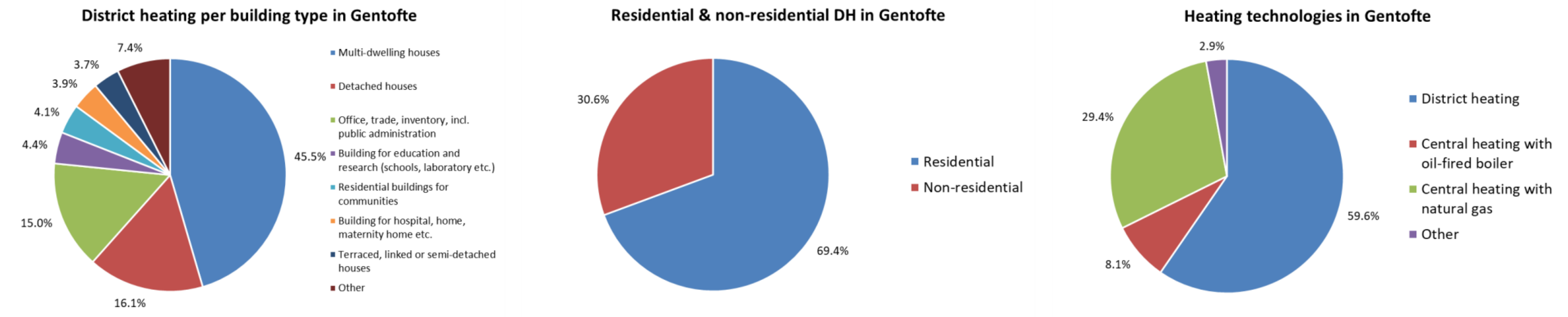


Figure 56 – DH per building type, building use of DH floor area and DH market share in municipality of Gentofte

Municipality of Gladsaxe

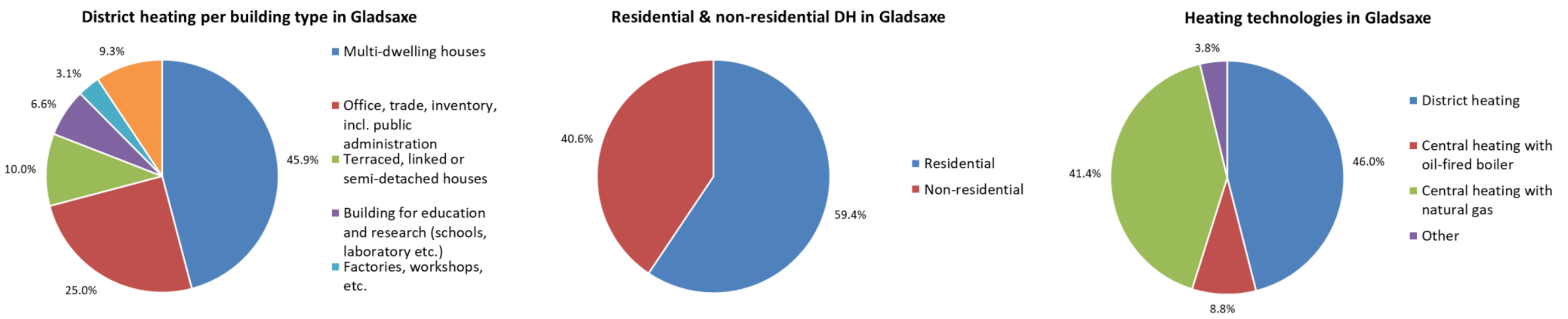


Figure 57 – DH per building type, building use of DH floor area and DH market share in municipality of Gladsaxe

Municipality of Tårnby

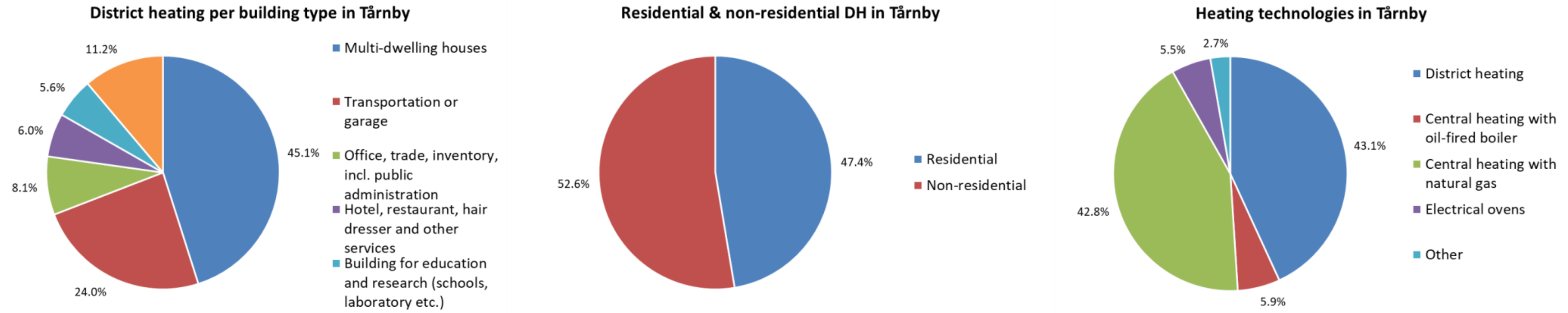
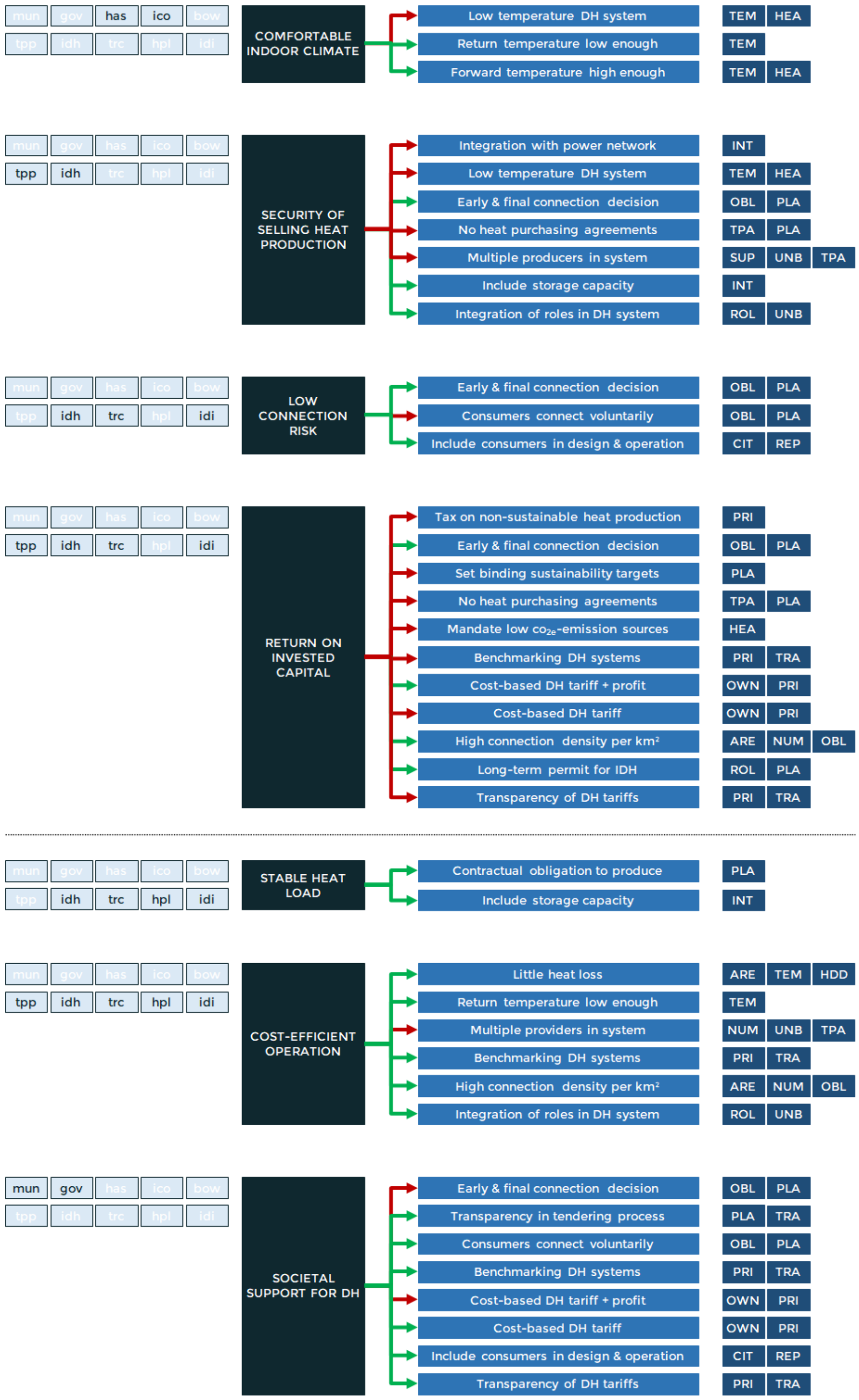


Figure 58 – DH per building type, building use of DH floor area and DH market share in municipality of Tårnby

F. Relationship between stakeholder interests and system requirements

OF INTEREST TO WHICH STAKEHOLDERS ?	STAKEHOLDER INTEREST	Relates how?	SYSTEM REQUIREMENT	RELATED FACTORS
mun, gov, has, ico, idh, trc, hpl, idi	SECURITY OF SUPPLY TO CONSUMER		Integration with power network	INT
			Multiple producers in system	SUP, UNB, TPA
			Include storage capacity	INT
			Contractual obligation to produce	PLA
has, ico, bow	LOW CONNECTION FEE		Transparency in tendering process	PLA, TRA
			Benchmarking DH system	PRI, TRA
			Cost-based tariff + profit	OWN, PRI
			Cost-based tariff	OWN, PRI
			High connection density per km²	ARE, NUM, OBL
			Transparency of DH tariffs	PRI, TRA
has, ico	LOW HEATING COSTS		Tax on non-sustainable heat production	PRI
			Mandate low CO_2e-emission sources	HEA
			Transparency in tendering process	PLA, TRA
			Multiple producers in system	SUP, UNB, TPA
			Multiple providers in system	NUM, UNB, TPA
			Benchmarking DH systems	PRI, TRA
			Cost-based tariff + profit	OWN, PRI
			Cost-based tariff	OWN, PRI
			Transparency of DH tariffs	PRI, TRA
mun, ico	FREEDOM OF CHOICE		Early & final connection decision	OBL, PLA
			Multiple producers in system	SUP, UNB, TPA
			Multiple providers in system	NUM, UNB, TPA
			Consumers connect voluntarily	OBL, PLA
			Integration of roles in DH system	ROL, UNB
			Long-term permit for IDH	ROL, PLA
mun, tpp	'OPENNESS' OF DH SYSTEM		Low temperature DH system	TEM, HEA
			No heat purchasing agreements	TPA, PLA
			Multiple producers in system	SUP, UNB, TPA
			Multiple providers in system	NUM, UNB, TPA
			Integration of roles in DH system	ROL, UNB
			Long-term permit for IDH	ROL, PLA
mun, gov, has, ico	SUSTAINABLE HEAT PROVISION		Integration with power network	INT
			Tax on non-sustainable heat production	PRI
			Return temperature low enough	TEM
			Mandate low co_{2e}-emission sources	HEA
			Little heat loss	ARE, TEM, HDD
			High connection density per km²	ARE, NUM, OBL
			Low temperature DH system	TEM, HEA
			Forward temperature high enough	TEM, HEA
			Set binding sustainability targets	PLA
gov	INNOVATION IN DH SECTOR		Integration with power network	INT
			Tax on non-sustainable heat production	PRI
			Set binding sustainability targets	PLA
			No heat purchasing agreements	TPA, PLA
			Mandate low co_{2e}-emission sources	HEA
			Transparency in tendering process	PLA, TRA
			Multiple producers in system	SUP, UNB, TPA
			Cost-based tariff + profit	OWN, PRI
			Integration of roles in DH system	ROL, UNB
			Long-term permit for IDH	ROL, PLA



LEGEND

mun	Municipality	ARE	Supply area	PRI	Price regulation
gov	National government	NUM	Number of connections	OBL	Obligatory connection
has	Housing association	SUP	Energy supplied	PLA	Planning
ico	Individual consumer	ROL	Role distribution	COS	Cost distribution
bow	Building owner	TEM	Temperature regime	CIT	Citizen participation
tpp	Third-party producer	HEA	Type of heat source	REP	Consumer representation
idh	Integrated DH company	UNB	Unbundling	TRA	Transparency
trc	Transmission company	TPA	Third-party access	HDD	Heat demand density
hpl	Heat planner	OWN	Ownership	INT	Integration of energy systems
idi	Indep. distribution comp.				

G. Relationship between system requirements and stakeholder interests

In the figures on the next two pages, all 24 suggested system requirements are presented on the left side. For each requirement the stakeholder interests that could be affected by these requirements are given and both are connected with either a green or a red arrow, representing a positive or a negative relation, respectively. Per interest the stakeholder types that share that interest – and thus are affected – are given, either in green or in red, on the right of the figure.

SYSTEM REQUIREMENT	STAKEHOLDER INTEREST	1	2	3	4	5	6	7	8	9	10
INTEGRATION WITH POWER NETWORK	SECURITY OF SUPPLY TO CONSUMER	mun	gov	has	ico			idh	trc	hpl	idi
	SUSTAINABLE HEAT PROVISION	mun	gov	has	ico						
	INNOVATION IN DH SECTOR		gov								
	SECURITY OF SELLING HEAT PRODUCTION						tpp	idh			
TAX ON NON-SUSTAINABLE HEAT PRODUCTION	SUSTAINABLE HEAT PROVISION	mun	gov	has	ico						
	INNOVATION IN DH SECTOR		gov								
	LOW HEATING COSTS			has	ico						
	RETURN ON INVESTED CAPITAL						tpp	idh	trc		idi
LITTLE HEAT LOSSED	SUSTAINABLE HEAT PROVISION	mun	gov	has	ico						
	COST-EFFICIENT OPERATION						tpp	idh	trc	hpl	idi
LOW TEMPERATURE DH SYSTEM	"OPENNESS" OF DH SYSTEMS	mun					tpp				
	SUSTAINABLE HEAT PROVISION	mun	gov	has	ico						
	COMFORTABLE INDOOR CLIMATE			has	ico						
	SECURITY OF SELLING HEAT PRODUCTION						tpp	idh			
RETURN TEMPERATURE LOW ENOUGH	SUSTAINABLE HEAT PROVISION	mun	gov	has	ico						
	COMFORTABLE INDOOR CLIMATE			has	ico						
	COST-EFFICIENT OPERATION						tpp	idh	trc	hpl	idi
EARLY & FINAL CONNECTION DECISION	SECURITY OF SELLING HEAT PRODUCTION						tpp	idh			
	LOW CONNECTION RISK							idh	trc		idi
	RETURN ON INVESTED CAPITAL						tpp	idh	trc		idi
	FREEDOM OF CHOICE	mun			ico						
	SOCIETAL SUPPORT FOR DH	mun	gov								
SET BINDING SUSTAINABILITY TARGETS	SUSTAINABLE HEAT PROVISION	mun	gov	has	ico						
	INNOVATION IN DH SECTOR		gov								
	RETURN ON INVESTED CAPITAL						tpp	idh	trc		idi
NO HEAT PURCHASING AGREEMENTS	"OPENNESS" OF DH SYSTEMS	mun					tpp				
	INNOVATION IN DH SECTOR		gov								
	SECURITY OF SELLING HEAT PRODUCTION						tpp	idh			
	RETURN ON INVESTED CAPITAL						tpp	idh	trc		idi
MANDATE LOW CO_2e-EMISSION SOURCES	SUSTAINABLE HEAT PROVISION	mun	gov	has	ico						
	INNOVATION IN DH SECTOR		gov								
	LOW HEATING COSTS			has	ico						
	RETURN ON INVESTED CAPITAL						tpp	idh	trc		idi
TRANSPARENCY IN TENDERING PROCESS	LOW CONNECTION FEE			has	ico	bow					
	LOW HEATING COSTS			has	ico						
	INNOVATION IN DH SECTOR		gov								
	SOCIETAL SUPPORT FOR DH	mun	gov								
MULTIPLE PRODUCERS IN SYSTEM	SECURITY OF SUPPLY TO CONSUMER	mun	gov	has	ico			idh	trc	hpl	idi
	LOW HEATING COSTS			has	ico						
	FREEDOM OF CHOICE	mun			ico						
	"OPENNESS" OF DH SYSTEMS	mun					tpp				
	INNOVATION IN DH SECTOR		gov								
	SECURITY OF SELLING HEAT PRODUCTION						tpp	idh			
MULTIPLE PROVIDERS IN SYSTEM	LOW HEATING COSTS			has	ico						
	FREEDOM OF CHOICE	mun			ico						
	"OPENNESS" OF DH SYSTEMS	mun					tpp				
	COST-EFFICIENT OPERATION						tpp	idh	trc	hpl	idi

Figure 59 – Relationships between system requirements, stakeholders and their interests (own illustration)

SYSTEM REQUIREMENT	Relates how?	STAKEHOLDER INTEREST	1	2	3	4	5	6	7	8	9	10
CONSUMERS CONNECT VOLUNTARILY		FREEDOM OF CHOICE	mun			ico						
		SOCIETAL SUPPORT FOR DH	mun	gov								
		LOW CONNECTION RISK							idh	trc		idi
INCLUDE STORAGE CAPACITY		SECURITY OF SUPPLY TO CONSUMER	mun	gov	has	ico			idh	trc	hpl	idi
		SECURITY OF SELLING HEAT PRODUCTION						tpp	idh			
		STABLE HEAT LOAD							idh	trc	hpl	idi
BENCHMARKING DH SYSTEM		LOW CONNECTION FEE			has	ico	bow					
		LOW HEATING COSTS			has	ico						
		COST-EFFICIENT OPERATION						tpp	idh	trc	hpl	idi
		SOCIETAL SUPPORT FOR DH	mun	gov								
		RETURN ON INVESTED CAPITAL						tpp	idh	trc		idi
FORWARD TEMPERATURE HIGH ENOUGH		COMFORTABLE INDOOR CLIMATE			has	ico						
		SUSTAINABLE HEAT PROVISION	mun	gov	has	ico						
COST-BASED TARIFF + PROFIT		INNOVATION IN DH SECTOR		gov								
		RETURN ON INVESTED CAPITAL						tpp	idh	trc		idi
		LOW CONNECTION FEE			has	ico	bow					
		LOW HEATING COSTS			has	ico						
		SOCIETAL SUPPORT FOR DH	mun	gov								
CONTRACTUAL OBLIGATION TO PRODUCE		SECURITY OF SUPPLY TO CONSUMER	mun	gov	has	ico			idh	trc	hpl	idi
		STABLE HEAT LOAD							idh	trc	hpl	idi
COST-BASED TARIFF		LOW CONNECTION FEE			has	ico	bow					
		LOW HEATING COSTS			has	ico						
		SOCIETAL SUPPORT FOR DH	mun	gov								
		RETURN ON INVESTED CAPITAL						tpp	idh	trc		idi
HIGH CONNECTION DENSITY PER KM²		LOW CONNECTION FEE			has	ico	bow					
		SUSTAINABLE HEAT PROVISION	mun	gov	has	ico						
		RETURN ON INVESTED CAPITAL						tpp	idh	trc		idi
		COST-EFFICIENT OPERATION						tpp	idh	trc	hpl	idi
INTEGRATION OF ROLES IN DH SYSTEM		SECURITY OF SELLING HEAT PRODUCTION						tpp	idh			
		COST-EFFICIENT OPERATION						tpp	idh	trc	hpl	idi
		FREEDOM OF CHOICE	mun			ico						
		"OPENNESS" OF DH SYSTEMS	mun					tpp				
		INNOVATION IN DH SECTOR		gov								
LONG-TERM PERMIT FOR IDH		SECURITY OF SUPPLY TO CONSUMER	mun	gov	has	ico			idh	trc	hpl	idi
		RETURN ON INVESTED CAPITAL						tpp	idh	trc	hpl	idi
		FREEDOM OF CHOICE	mun			ico						
		"OPENNESS" OF DH SYSTEMS	mun					tpp				
		INNOVATION IN DH SECTOR		gov								
INCLUDE CONSUMERS IN DESIGN & OPER.		LOW CONNECTION RISK							idh	trc		idi
		SOCIETAL SUPPORT FOR DH	mun	gov								
TRANSPARENCY OF DH TARIFFS		LOW CONNECTION FEE			has	ico	bow					
		LOW HEATING COSTS			has	ico						
		SOCIETAL SUPPORT FOR DH	mun	gov								
		RETURN ON INVESTED CAPITAL						tpp	idh	trc	hpl	idi

Figure 60 – Relationships between system requirements, stakeholders and their interests, continued (own illustration)