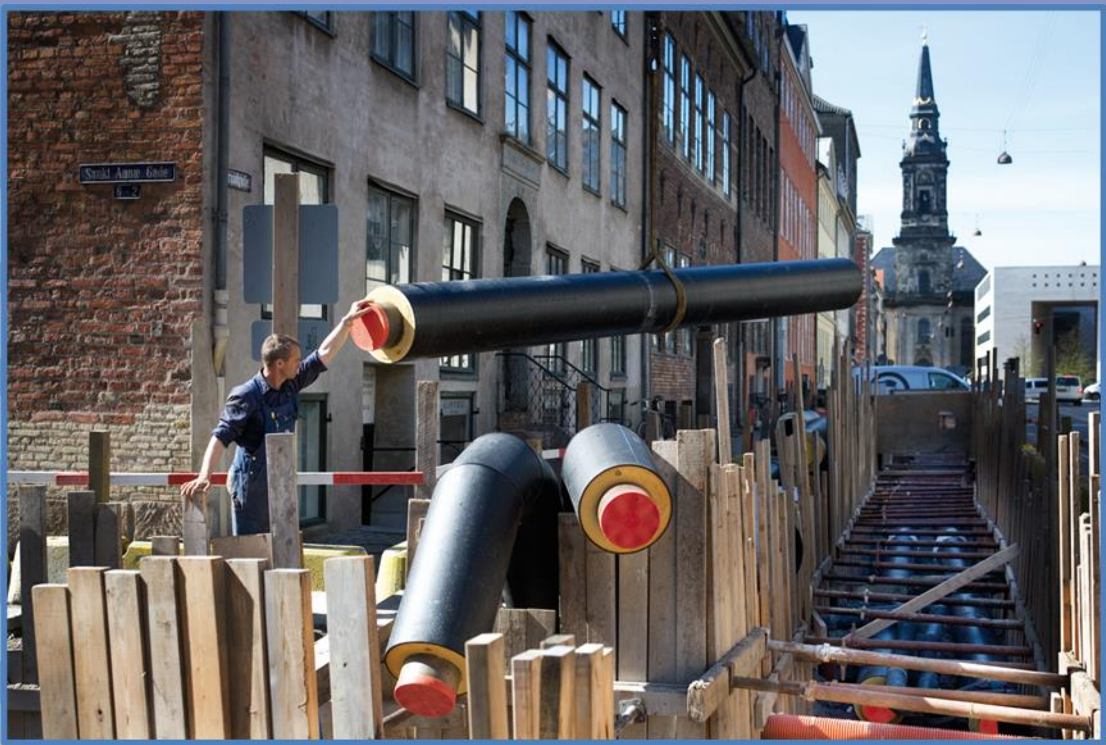
Best practices for planning and construction of thermal networks identified in the EU

External study performed by
TNO and DBDH
for the Joint Research Centre



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Disclaimer
All data in this report has been researched and compiled with the utmost diligence by TNO and DBDH experts. However, the possibility of errors and mistakes cannot be totally excluded.

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Foreword

This study was made by TNO and DBDH for the JRC with the aim to establish some best practices in the planning and construction phases of district heating and cooling networks.

Acknowledgements

The authors would like to thank Johan Carlsson of JRC and his team for the valuable feedback throughout the entire study. The best practices resulting from this study are based on the experiences of district heating companies and municipalities in eight different EU countries. We are very grateful to the experts of the district heating operators and from the municipalities involved in the case studies for sharing their lessons learned and for being so open during the interviews. See the list of interviewees in the table below.

Last but not least the discussions with the Expert Panel provided input on the topics we should prioritise and strengthened our recommendations based on their view and own experiences. So, thank you Lars Gullev (Veks – Vestegnens Kraftvarmeselskab, Denmark), Gijs de Man (SVP – Stadsverwarming Purmerend, Netherlands), and Max Peters (KEA-BW – Klimaschutz- und Energieagentur Baden-Württemberg, Germany).

Table 1 List of Interviewees

Location	Name of interviewee	Function
Storvorde near Aalborg, Denmark	Jesper Møller Larsen	Head of District Heating, Ålborg Utilities
	Anita Rosenkilde-Lodberg	Energyplanner, Municipality of Aalborg
Antwerp, Belgium	Tom De Bruyckere	Advisor, ISVAG
	Paul Robbrecht	Project manager, Province of Antwerp
Salaspils, Latvia	Roberts Kaķis	Data analyst at Salaspils Siltums
	Helmuts Alksnis	Head of Production Processes and Development Department
	Ilze Polikarpova	Manager of Functionality Department
	Raimonds Čudars	Chairman council Salaspils Municipality
Drechtsteden, Netherlands	Luc Brugman	Strategy Heat Transition, HVC
	Joey Reedijk	Program Manager, Drechtsteden
A2A Smart City, Milan, Italy	Alessandro Capretti	Head of District Heating Network Planning and Design ,A2A
Bruchsal, Südstadt	Armin Baumgaertner	Managing Director Stadtwerke Bruchsal GmbH
	Hartmut Ayrle	Leiter Fachbereich Stadtentwicklung, Stadt Bruchsal
Mostoles, Madrid	Roberto de Antonio	Founding partner, Mostoles District Heating
MPEC, Olsztyn	Konrad Nowak	CEO of MPEC Olsztyn
	Dariusz Mikulak	Municipality of Olsztyn

1 Executive Summary

This study aims at gathering experiences and identifying best practices in both the urban planning and construction phases for thermal networks (district heating) in the built environment. The lessons learned should help local governments and new potential district heating operators in developing new thermal networks or accelerating the expansion of existing networks.

The results of this study are based on eight case studies of thermal networks in existing residential and service sector neighbourhoods, since 2015. These cases are geographically spread over the EU, and cover a variety of heating technologies.

Table 2. Overview of case studies.

Case study	Country	Year of implementation	Type of district	Type of project	Owner	Previous experience	No. Connections (housing units)
Storvorde near Aalborg	Denmark	2020 - 2022	Combined area	Extension	Public	DH company: Extensive Municipality: Extensive	Current: 1 800 households Extension: 300 households
Antwerp	Belgium	2019-2020	Service Area	Stand alone	Commercial / Public	DH company: None Municipality: None	At this stage industrial clients (up to 3MW). Extension (potential): 40 000 dwellings
Salaspils	Latvia	2018-2020	Combined area	Stand alone	Public	DH company: Extensive Municipality: Extensive	172 connections (equals approx. 5 000 dwellings)
Drechtsteden	Netherlands	2019-2025	Residential area	Extension and Stand alone	Public	DH company: Extensive Municipality: Limited	Current network 1 296 dwellings and 4 421 non-residential home-equivalents Extension (potential): 5 930 dwelling-eq.
A2A Smart City, Milan	Italy	2014-2020	Residential area	Extension	Commercial	DH company: Extensive Municipality: Limited	Current : 166 000 flat equivalents Extension: size unknown
Bruchsal, Südstadt	Germany	2017-2021	Combined area	Stand alone	Public	DH company: None Municipality: None	2 schools, seniors retirement home, medical centre, 20 flats
MPEC, Olsztyn	Poland	2019-2023	Combined area (mainly housing)	Extension	Public	DH company: Extensive Municipality: Extensive	Current: 60 000 home-equivalents Extension: 1 650 heating units and 2 500 houses
Mostoles, Madrid	Spain	2017	Combined area	Stand alone	Commercial	DH company: Medium Municpality: None	117 connections (equals 2 422 housing units)

Interviews with both the district heating operators as well as with representatives from the municipalities of these cases have been performed to learn from their experiences in both phases. Despite the differences in the eight cases quite a number of lessons could be grouped in 5 categories of general best practices, i.e. business case and costs, governance, social acceptance, regulation, policy and subsidy, and a group of other strategic items. These best practices are summarised below for the planning phase and the construction phase respectively.

The best practices can be boiled down to maybe one, mentioned by almost all interviewees: “Do your planning very well and include all relevant parties in a constructive process. Then construction will be easier, and the best system will be in place”. This might oversimplify the main result, but at the same time demonstrates how important the planning phase is in creating a successful district heating project.

Table 3. Identified best practices for the planning phase.

Category	General best practices for the planning phase	Context
Business case and costs	Start planning with large consumers.	This can make the business case and it allows for organic growth: first establish a network with large consumers and then expand to the smaller consumers. Furthermore, the entry level (percentage of consumers who have been contracted before construction starts) can be lower.
	Focus on locally available renewable energy sources and/or waste energy sources.	Necessary for the heat transition. It was mentioned several times that there is still a lot of untapped heat potential. It will make a DH network more futureproof. Each location and project is different, so the solutions will be different everywhere. Look at what is available locally.
	Work together with other utilities.	This was mentioned several times and it mainly reduces cost. Different perspectives: in some cases only when it occurs, in other cases this collaboration with other utilities dictates the planning of DH. As a sidenote, cases are known in which this collaboration has actually delayed the construction of DH and increased the cost, so one has to be sure that the planning aligns.
	Have a clear risk and responsibility package from the beginning.	Important to do this during the planning phase, to avoid trouble during the construction phase and to help in settling disputes.
	Visualise the business case from the start, including what a change in conditions will do.	Changes are bound to happen, is the business case still positive if these changes occur? What can be done to counter these changes?
Governance	Have a long term heat strategy.	Do not only focus on one project, but have a longer horizon, e.g. for organic growth of a DH network.
	Have an overview of public buildings with a large energy demand.	This can give indications on what are good places to start a DH network. Can also be extended to include private buildings or business parks. Furthermore, these buildings can be seen as long-term consumers.
Social acceptance	Communication prior, during and after project execution with local stakeholders.	Ensure people are updated on the process, educate them (on sustainability and DH) and make them enthusiastic for DH.
	Involve the local population during the planning phase.	This goes one step further then informing people. Also listen to their concerns and take these into account.
	Take away the investment barriers for customers, e.g. by leasing the heat delivery set.	High entry-cost, e.g. connection cost, will prevent uptake and hence influence both the business case and a city's sustainability agenda.
Regulation, policy and subsidy	Have a smooth process for approvals from the municipality.	In some cases we saw that communication between operators and municipalities was arduous, mainly because there were several departments within the municipality which had to be contacted. A smooth process will reduce time and costs.
	Policy should have a guiding role.	Both on a national and local level. Both can give subsidies and support to make DH possible and have influence on it, e.g. renewable heat sources and communication with the people. Regulation can also help, e.g. new buildings cannot be heated by gas. Local governments should have a long term heat plan which can include DH. A positive climate for DH will also help with social acceptance.
	Use EU support funds to finance projects in relatively low income countries.	Low-income countries benefit from subsidies from EU-funds.
Other strategic items	When you lack knowledge or experience, collaborate with (international) partners who do have this knowledge and experience.	There are different levels of expertise between countries, municipalities and projects. Be sure to involve others when lacking expertise. Important to do this from the beginning of the project. Focus also on acquiring knowledge during the project.
	Take your time for the planning phase.	Most cases mentioned that if the planning phase is executed correctly, then the construction phase is "easy". And if hiccups occurred during the construction phase, then usually the solution was to spend more time during the planning phase.

	A transparent process and joint commitment of the stakeholders involved.	It is important to have a transparent process. This will ensure acceptance of the project. The stakeholders should agree on the plan.

Table 4. Identified best practices for the contstruction phase.

Category	General best practices for the construction phase	Context
Business case and costs	Adhere to the best available technology.	What the best available technology (BAT) is might differ between projects. It is a balance between investment costs, operational costs and other relevant criteria such as sustainability. Investigate your options and choose the one that is best according to your criteria. It is good to share knowledge and have clear EU standards. Note that BAT is not necessarily the most advanced, e.g. extreme low temperature, but can also be best available well tested and documented technology. It can also depend on the experience of the ones involved in the project.
	Work together with other utilities.	Similar to the general best practice in the planning phase. It can reduce costs.
	Lower the supply temperature to increase efficiency.	Still high temperature grids are being built, while low temperature (LT) grids have a much higher efficiency. Also LT grids are able to use more sources, such as the waste heat of nearby buildings. This will also make the grid futureproof.
	Be prepared for hiccups.	Connects to the clear responsibility package as mentioned in the planning phase. Being prepared for hiccups will decrease the delay and costs. Important to learn from others and previous projects on what are typical hiccups.
Social acceptance	Only do construction outside winter period.	Depends on the location, in a cold climate this can be an important general best practice, while in warmer climate it is not as important.
	Co-ordinate with utilities to cause less disruption.	Working together will utilities not only reduces the costs of the project, but also limits the disruption caused by construction. As such, it can improve the social acceptance of DH, e.g. by avoding traffic disturbance.
	Execute project in phases to minimise disruption to normal city life.	Depends on the location, in a busy city centre it is important, in a small town it is not as important.
Other strategic items	Have regular co-ordination meetings.	This was especially mentioned by cases in which this was not done. Then the overview of the project can be lost quickly.
	Put more time in the project to create bonds with partners for future projects.	This general best practice is especially important for parties which are new to DH. Invest time in the first projects, such that future projects will go smoother.

These general best practices can be used almost as a check list. But not a check list where all points have the same relevance for all situations. So, evaluate the importance of each best practice for your project.

This guideline was also confirmed during the workshop with all the interviewees. The list of best practices can ensure a successful project, when used as a reference list that especially cities with less experience can use and will help them in having a smoother and better planning and construction phase. Another conclusion was that the list can be used to identify and select the best practices that are most suitable for a specific project. Not only at the beginning but to be reassessed regularly, to check if these are still the most relevant ones, and to adjust the project accordingly.

This report highlights a series of best practices that all district heating projects can benefit from using. The research also showed that good, careful planning is essential. Some even said that planning is the only best practice needed. The report also points towards further research valuable for future district heating especially regarding planning. Better insight into good planning cases, planning methodology and planning legislation could potentially help EU cities and district heating companies reach their goals in better, less expensive and faster ways.

2 Introduction – lessons learned from district heating projects

To support speeding up the expansion of district heating and cooling in Europe, this study provides some good practices and guidance to local governments and potential district heating operators. Despite the many positive aspects, several barriers prevent the expansion of thermal networks. For example, it is a complex and large undertaking to develop thermal networks, which requires support from local authorities that have a long-term heat strategy.

The energy and climate policy of the EU aims at a large share of renewables in the energy mix. The revised Renewable Energy Directive set a target to reach at least 32% energy generation from renewables by 2030, of which 40% is projected to come from renewable heating. Expanded use of thermal networks could help achieving both those goals.

This study aims to gather experiences and identify best practices in both the urban planning and construction phases for thermal networks (district heating) in the built environment.[1] Are there any practices that could be replicated? What were the differences in approaches? The target audience is local governments and new potential district heating operators.

Lessons learned should help local governments and new potential district heating operators in developing new thermal networks or accelerating the expansion of existing networks. To this end, experiences have been gathered and best practices have been identified in both the urban planning and construction phases for thermal networks in the built environment. Besides, differences in approaches are part of the outcome, including an explanation of the nature of these differences, e.g. the way the energy landscape is organised in a country. This report provides recommendations based on the experiences of the eight case studies and describes which best practices can be replicated including the boundary conditions that need to be in place.

The results of this study are based on eight case studies of thermal networks in existing residential and service sector neighbourhoods, since 2015. These cases are geographically spread over the EU, and cover a variety of heating technologies.

This study builds on two previous JRC studies. The first one, performed in 2016, investigated key success factors enabling the development of high quality, efficient and low-carbon district heating and cooling systems. The second study, on the incorporation of sustainable heat sources to modern thermal networks, was finalised in February 2021.

Planning versus construction phase

This study focuses on the planning and construction phases. The planning phase can start in multiple ways: a district heating company finds an interesting location and starts evaluating the possibilities, a municipality wishes to have more district heating and sets out a tender or contacts a district heating company, etc. Once the idea for district heating is there, goals have to be defined and the feasibility of the plan has to be checked. This will be done by several stakeholders, e.g. a district heating company or other initiators, a municipality, a company that provides heat or owns a heat source, consumers with a large heating demand, etc. Next, the design of the district heating grid takes place. This can be done with the help of engineering consultants. Planning phases can differ between countries, municipalities and projects. For example, in Denmark it is mandatory for the district heating company to perform a socio-economic analysis to show that district heating is the best option for society. This analysis is checked by the municipality. Such an analysis is a standard part of the planning phase in Denmark, but is not often seen in other countries. The level of involvement of the public during the planning phase also differs. When the design of the district heating network is completed, the necessary permits have to be collected. Also, tenders have to be set up for companies to execute the construction.

The construction phase starts when all permits are in place, and the final investment decision has been made. A construction company has to be selected, contracts have to be settled, etc. During the construction phase all components of the thermal network are constructed and the heat sources and clients are connected to the grid. There can be some iterations between the construction and planning phase when hiccups occur.

The interviews show that most lessons can be learned from the planning phase.

[1] The (urban) planning phase often covers the period from initiative until the investment decision made by the district heating company or other investors. The construction phase is the period of building a thermal network until first delivery of heat to clients. Best practices are defined as lessons learned from experts they recommend others to apply in their district heating developments.

Reading guide

The report is organised in five main sections. After presenting the methodology used for the study in Section 3, the results of the investigations of the eight selected case studies are described in Section 4, followed by the analyses of these cases as well as the cross-case analysis in Section 5. The latter includes best practices in both the planning and construction phase in district heating. Feedback on the results from the interviewees and from the Expert Panel can be found in Section 6. Finally, Section 7 provides the conclusion of the study and dos and don’ts when developing a district heating project.

The project team

TNO (Netherlands Organisation for Applied Scientific Research) is an independent research organisation. We connect people and knowledge to create innovations that boost the sustainable competitive strength of industry and well-being of society. For this purpose, TNO is established by law as legal public entity. The TNO-law allocates certain tasks and responsibilities to TNO while also providing the parameters for the execution. The reasoning behind it is to safeguard TNO’s independent position to conduct the research needed to create reliable solutions for the challenges society faces.

TNO is working with energy companies, existing industries and new players in district heating, national and local governments, consultants and other research organisations on district heating, regularly in a public-private partnership. Projects cover technical, economic, institutional or societal aspects.

DHBD (Danish Board of District Heating) is an independent trade organisation with the mission to promote district energy for a sustainable city transformation. DBDH represent the leading actors of the district energy sector, and identify, inform and facilitate partnerships between our members and partners in more than 70 countries.

3 Methodological approach – interactive feedback loops

In order to gather experiences and identify best practices in developing district heating a mixture of desk research and interviews has been applied. The former has been used to find general information about the potential use cases and about national energy policy and regulations. The latter to provide in-depth insights in business cases and costs, governance, social acceptance, and regulation, policy and subsidies for district heating. The interviews were conducted with project managers of district heating companies and municipalities provided detailed information about their practical experiences and their lessons learned during the (urban) planning phase and the construction phase of a thermal network.

Our approach is built on a number of feedback loops in which information is used to improve a first result, e.g. use short interviews to extend and alter the long list of use cases or to use the outcome of in-depth results to adjust a questionnaire. In general, this approach is depicted in the scheme of Figure 1. This figure also shows the four different work packages of this study. The various elements in each of the boxes are described in more detail in Sections 3.1 to 3.4. In general, our methodological approach consists of the following key elements:

- Select use cases. Long list of potential cases, case selection on objective selection criteria.
- Analysis of selected cases. Standardised question lists. Interviews with different stakeholders in each use case, with different interests and visions. Analysis and deep knowledge of cases that have been described in the literature mentioned above.
- Best practices and recommendations. Reflection on these cases and their key success factors. Reflection on the methods used. Thorough review of the results of the study by international experts and stakeholders.
- Dissemination. Share results with JRC, our contact persons, and a larger target audience.

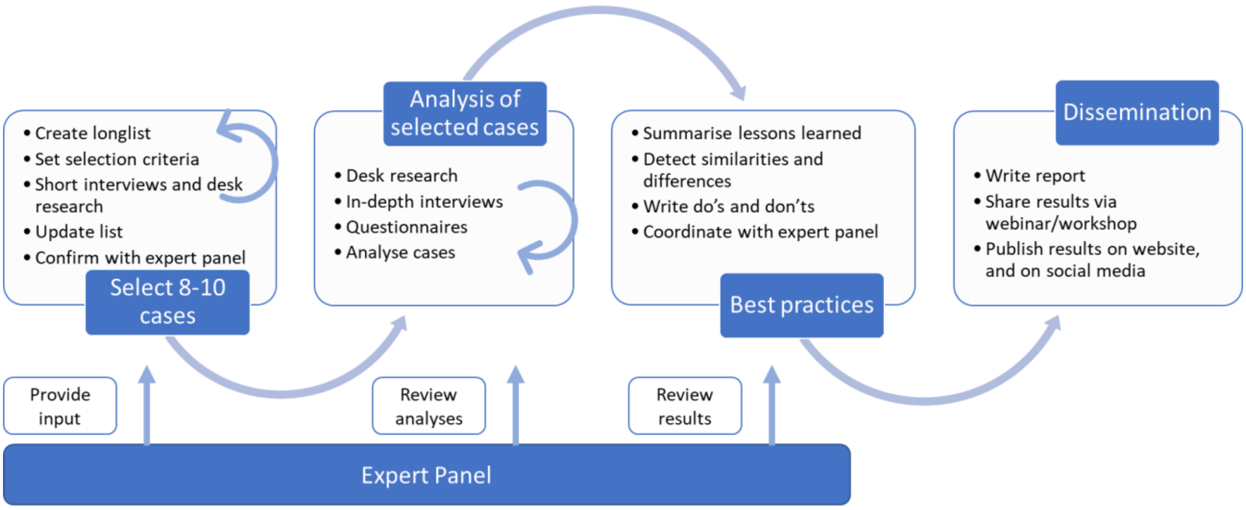

Figure 1. Schematic overview of our approach, TNO (2021).

Special attention has been given to make use of the communication with the contact persons of the case studies. This is also used for the feedback loops. Interviews were also used to adjust first results, e.g. to adjust the list of cases during the first weeks of the project and to improve questionnaires during the stage of information gathering.

However, it is also very important to demonstrate to the interviewed persons that they will benefit from taking the time to participate. Not only have these persons been asked to check whether the analysis about their own case is right, they have also been informed about the results of the other cases so they can learn from others as well. To this end, a webinar has been organised with all the participating cases in which the results from the study were presented, shared and discussed.

3.1 Selection process of the use cases

The aim of this first step was to select eight use cases which are expected to largely contribute to best practices that future district heating projects can benefit from. Taken together, the cases should also provide a well-balanced mix to get as many lessons as possible.

Selection criteria

Enough cases needed to be collected in the beginning to ensure a heterogenous list of cases covering the most important aspects of the planning and construction phases. For example, the list included cases where the main project consists of an extension to already existing networks where the need to establish new fuel sources can be less or where enough heat capacity is available. The following criteria have been used in the selection process:

- Geographical spread throughout the EU;
- Level of experience with district heating in the country;
- Different type of areas or type of customers, i.e. residential area, service sector neighbourhoods or combinations of these areas;
- Different district heating technologies (main heat source), including renewable heat sources or a mix of heat sources;
- Type of project, i.e. stand-alone thermal network or extension of existing network;
- Size of the projects in terms of number of connections (housing units);
- Different types of ownership.

The willingness to contribute to this study and to co-operate with the project team has been checked before adding a project to the longlist. It appeared that many contact persons showed a strong interest in the study and found the potential recommendations to be beneficial to them for future projects.

From longlist to eight use cases

The experience with district heating research has been used to ensure a geographical spread of use cases for this study. For example, in a recent analysis TNO noticed several differences in the way district heating systems are organised and in financial schemes due to differences in culture, history in energy landscape, and national policies.

The selection process started with developing a long list of potential use cases of projects starting or expanding in 2015 or later. An open invitation to our large European network of district heating companies and local authorities was applied to broaden the base of potential examples of lessons learned. The project should cover the most important aspects of the planning and construction phases as well as cover both residential areas and service sector neighbourhoods. The result was a heterogenous list of 30 district heating projects.

A desk study has been performed to add all relevant information to these projects in order to identify the most relevant cases for this study. This included both an internet search and data collection via phone and email.

After completion of all data for each criterion a draft selection was made and discussed with the Expert Panel first and then with the JRC. As a result, small changes were made to the shortlist.

The result is shown in Chapter 4, and a more detailed version in Appendix A.

3.2 Information gathering and analysis methodology for the selected cases

Information gathering

The second part of the study started with gathering information about the eight use cases via additional desk research to create a good base on the history and context of the project, also to be used as a base before starting an interview. In parallel, a primary questionnaire was sent to the persons working on these district heating projects to learn about their priorities during both phases of their project. Besides, desk research was carried out to make an inventory of recent and new trends in national policy, the energy landscape, and other relevant information like societal acceptance.

Detailed information about the experiences of these projects, both during the urban planning and the realisation phase, has been derived by in-depth interviews with key people for each case. To this end a guiding set of questions was set up to ensure the key elements of district heating projects would be addressed during the interviews, i.e. business case and costs, governance, social acceptance, and regulation, policy and subsidy. As the project team learned about the practical value from the first interviews, slight adjustments were made in the questionnaire.

In all cases the project manager or other senior experts of the district heating project were interviewed. In six cases additional interviews were conducted with the representative of the municipality or province to get input from another stakeholder. It provided additional insights about the findings of the development of the district heating project in their case.

The results of the information gathering are described in Sections 4.1 to 4.8.

Analysis methodology

The aim of the research is to find best practices, success factors and failures. Therefore, the most important questions to ask are whether the project was a success and how the urban planning and construction phases contributed to the success. Directly connected to that is to investigate what elements could have been done better. These are the prime conditions to evaluate at a later stage, and the basis for understanding how that could be incorporated into the recommendations. Note that best practices and success factors are subjective terms. It was left to the interviewees what they regard as a best practice or as a success factor or an aspect that can be improved. Also, each interviewee decided themselves what was needed to make their practice a best practice.

In close co-operation with the Expert Panel and the JRC team the following aspects were focused on:

- Business case and costs;
- Governance of the project;
- Social acceptance and the way local citizens and other potential users e.g. in the service sector are involved in the project development;
- Regulation, policy and subsidy.

The focus changes when the project is moving from the planning to the realisation phase. In the urban planning phase, the focus is on policy, co-operation between local authorities and potential district heating operators, social acceptance, and business cases. In the construction phase, economics and technology will be of more importance although this appears to be somewhat different in the various cases. In general, more attention has been paid to the planning phase as it quickly became clear that more lessons can be derived from this phase than the realisation phase.

In some of the interviews one or two other aspects were mentioned as important lessons and thus potential best practices as well.

The approach was to systematically structure the data from the interviews, and to make a proper understanding of success factors in the planning and construction phases of thermal networks in the built environment. Therefore, it was needed to create a deep understanding of each case, one by one. The analysis resulted in an overview of identified best practices per case which can be found at the end of each of the case descriptions in Chapter 4.

3.3 Determination of best practices and recommendations

An overview of best practices of the eight use cases is shown and described in Chapter 5. Additionally, a cross-case analysis has been performed to extract general trends from the “case-by-case” analyses and convert this into more universal best practices (key success factors) and recommendations.

The results of the cross-case analysis has been used as input for recommendations how others can make use of best practices in future projects, both in the urban planning and the construction phase. This in included in the “dos and don’ts” in Chapter 7.

It appears to be difficult to appoint the influence of different factors in the system, such as culture, legislative framework, level of experience of district heating in the country, and ditto in the local government. The variety of thermal networks in a country let alone in the EU is just too large. So, some of the best practices in this report might be more applicable to their situation than others. Nevertheless, as a result of the cross-case analyses general best practices and recommendations have been derived next to specific ones for the various kinds of district heating projects.

The experience of the Expert Panel members in decision making in a large number of district heating projects has been used to discuss the prioritisation of the results from the analyses, and to apply more practical wordings in our recommendations.

3.4 Dissemination of the results

The project team has been in close contact with the contact persons of the use cases throughout the project. They were interviewed to check the result of the interview, and to join a workshop with all interviewees asked to discuss the overall results of this study and discuss the results among each other.

As the indirect goal of this study is to speed up the expansion of district heating and cooling in the EU, and in addition to the workshop for the contact persons, the following activities have been organised in close co-operation with the JRC:

- A webinar for local governments and potential district heating operators in the EU in which the results of this study are shared;
- Adding the final report of this study to the energy.nl and dbdh.dk websites,[2] and promotion of it on social media, e.g. LinkedIn;
- The project results will also be shared via articles to be published in DBDHs magazine Hot Cool reaching out to approximately 8 000 readers.

[2] TNO is operating the energy.nl website in which project results and other relevant studies are shared with experts and others interested in renewable energy and related topics.

4 Presentation and study of the eight cases

To identify best practices of urban planning and construction of district heating, eight cases are studied, see the table and map below. In this chapter, the eight cases are presented. For each case, first the historical and current background of district heating in the country of the case is described. Second, an overview of the regulatory framework is provided. Next, the project is described, based on the interviews for each case and other information sources. Finally, preliminary success factors are identified for each case. In the next chapter a cross-case study is performed.

The eight cases were selected based on the selection criteria mentioned in Section 3.1. The focus was on selecting cases that would combine values and selection criteria in different ways. The Table 5 below show that the cases cover a wide variety in each of the criteria. Effort has been made to both find and convince a wide variety of projects to take part, resulting in a rather heterogeneous set of eight cases. The geographical spread is wide, the study covers service and residential areas and a combination, half are standalone and half are extension projects, and the amount of experience the company and the municipality had before entering into the project also varies.

For a few criteria it can be difficult to determine the exact value. Most important is if the owner is public or commercial. Here the thermal network (or district heating) operator range from strictly public e.g. owned by the municipality to strictly commercial companies. The publicly owned operators have no options to make any profit to any stakeholders. The commercial companies are developing district heating projects with the intention to optimise profit and eventually sell to others. In between these there are companies owned by a group of municipalities having as a goal to maximise profits and others who seem in private ownership but acting more like a not-for-profit organisation. However, the team has simplified this in the column “owner”. In the end, the difference in ownership didn’t seem to result in other best practices as many other factors play a role. It is the team’s belief that the best practices identified later cover both types of ownership.

Also previous experience is difficult to measure. A municipality with no or limited experience, but making a strong effort to engage external expertise, will have experience, but still the decision making and the deeper experience may be lacking. Therefore the previous experience is rated on three simple levels: None, Limited and Extensive.

Table 5. Overview of the eight selected use cases.

Case study	Country	Year of implementation	Type of district	Type of project	Owner	Previous experience	No. connections (housing units)
Storvorde near Aalborg	Denmark	2020 - 2022	Combined area	Extension	Public	DH company: Extensive Municipality: Extensive	Current: 1 800 households Extension: 300 households
Antwerp	Belgium	2019-2020	Service Area	Stand alone	Commercial / Public	DH company: None Municipality: None	At this stage industrial clients (up to 3 MW). Extension (potential): 40 000 dwellings
Salaspils	Latvia	2018-2020	Combined area	Stand alone	Public	DH company: Extensive Municipality: Extensive	172 connections (equals approx. 5 000 dwellings)
Drechtsteden	Netherlands	2019-2025	Residential area	Extension and Stand alone	Public	DH company: Extensive Municipality: Limited	Current network 1 296 dwellings and 4 421 non-residential home-equivalents Extension (potential): 5 930 dwelling-eq.
A2A Smart City, Milan	Italy	2014-2020	Residential area	Extension	Commercial	DH company: Extensive Municipality: Limited	Current : 166 000 flat equivalents Extension: size unknown
Bruchsal, Südstadt	Germany	2017-2021	Combined area	Stand alone	Public	DH company: None Municipality: None	2 schools, seniors retirement home, medical centre, 20 flats

MPEC, Olsztyn	Poland	2019-2023	Combined area (mainly housing)	Extension	Public	DH company: Extensive Municipality: Extensive	Current: 60 000 home-equivalents Extension: 1 650 heating units and 2 500 houses
Mostoles, Madrid	Spain	2017	Combined area	Stand alone	Commercial	DH company: Medium Municpality: None	117 connections (equals 2 422 housing units)

The cases are described in the following eight sections 4.1 to 4.8. Each section starts with the interesting characteristics of the district heating project, and the reason this case has been selected. The historical and current background of the project is next, followed by the regulatory aspects of the country concerned. The largest part of this section concerns a description of the case study based on the interviews with the district heating operator and, which in most cases, is the point of contact at the municipality. Each section ends with the lessons identified from this project. An overview of the locations can be found in the map below.

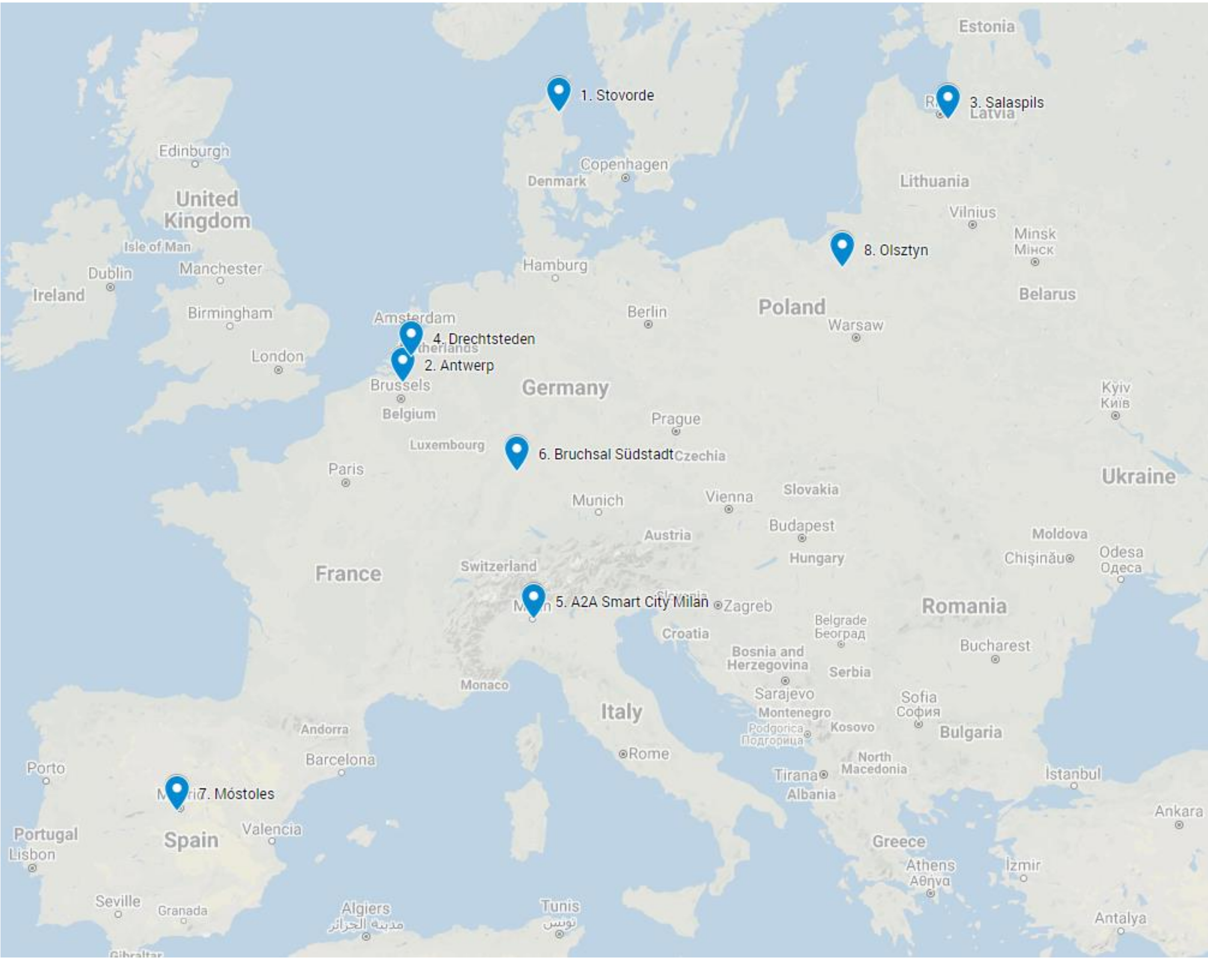

Figure 2. Locations of the eight selected use cases (map created with Google Maps), TNO (2021)

4.1 Storvorde, Aalborg

Stovorde is a small town in the municipality of Aalborg in Denmark. This project is an example of a small project being added to a large existing system. Also, a combination of heat sources is used in this network.

The length of the history in district heating in Denmark as well as the step-by-step expansion of the thermal network in Aalborg and thus many years of experience, makes this case interesting.

4.1.1 Historical and current background

For an extensive description of the historical and current background of district heating in Denmark we refer to DEA (2017). In this section we give a brief overview.

The first extended DH networks appeared in Denmark in the 1920-1930s, where the heat from CHP plants was used to heat households. District heating experienced a boost in the 1970s thanks to policies to secure supply following the oil crisis in 1973 (JRC, 2016). In 1979 the first heating supply Act was passed. The increase in DH was also supported by the rise of CHP fuelled by gas thanks to the discovery of abundant reserves of this resource in the North Sea (Galindo et al., 2016). Later, cogeneration became essential in the Danish energy mix thanks to the "Co-generation agreement" in 1986, where a minimum installed capacity of CHP was established for energy utility companies to fulfil. In the 1990s renewable sources for heat supply, such as biomass, were boosted through taxes on fossil fuels for heating and policies such as the Biomass Agreement in 1993.

Nowadays, Denmark is a leading country in the development of DH. The market share of DH was 64% in the residential sector in 2017, with 400 networks constructed (Galindo Fernandez et al., 2021). From these systems, 84% is covered by consumer co-operatives, followed by municipal companies (12%) and the rest commercial companies (Gorroño-Albizu et al., 2019). The future of DH in Denmark is now headed towards the decarbonisation of DH through the integration of renewable sources and waste heat, especially wind energy, and the reduction of costs (Boscan & Söderberg, 2021).

4.1.2 Regulatory framework

At national level, the most important policy regarding DH is the Heat Supply Act, first introduced in 1979. This Act establishes that municipalities are responsible for the development of municipal heat plans, considering the current and future heat demand. Until 2018, the municipality could oblige the citizens under the heat plan zoning to connect to the grid (Galindo Fernandez et al., 2021). The approval of the DH project by the municipalities, according to the law, should be made according to socioeconomic costs (DEA, 2017).

The DH market is regulated under the Heat Supply Act. A not-for-profit principle is established. The law defines which costs can be included in the heating price: capital expenditure, operations and maintenance, fuel price, heat losses and costs related to efficiency improvement (Boscan & Söderberg, 2021; DEA, 2017). This ensures protection of consumers against abusive tariffs due to the monopoly nature of DH.

The institutions in charge are (Galindo et al., 2016; DEA, 2017):

- the municipalities, owners and operators of the DH network through municipal heat companies;
- the Energy Board of Appeal, which responds to complaints about prices;
- the Danish Energy Regulatory Authority, responsible for the voluntarily annual benchmarking of heat companies to ensure efficiency and to reduce prices.

Other influential regulations are the National Energy and Climate Strategy and the Energy Savings Obligation Scheme (Galindo Fernandez et al., 2021).

Subsidies and taxes also play an important role in the implementation of DH. As mentioned before, tax exemptions in biomass and other sustainable sources have supported cleaner DH systems. Decentralised CHP plants were subsidised during the 1990s and currently have a premium tariff on top of the electricity subsidy in case of CHP fuelled by gas and waste, or as an add-on a surcharge paid by electricity consumers if fuelled by biomass or biogas (Galindo et al., 2016).

4.1.3 Case study

Since 2019, Storvorde, a small town located in the southeast of Aalborg, has been connected to the town's existing DH network. Figure 3 shows an overview of the main pipeline for Storvorde and the zones for intermediate pipes.

Figure 3. Map of the planning of the main pipeline for Strovorde (left) and zones for the intermediate pipes and its respective estimated time of construction (right) (Aalborg Forsyning, 2021b)

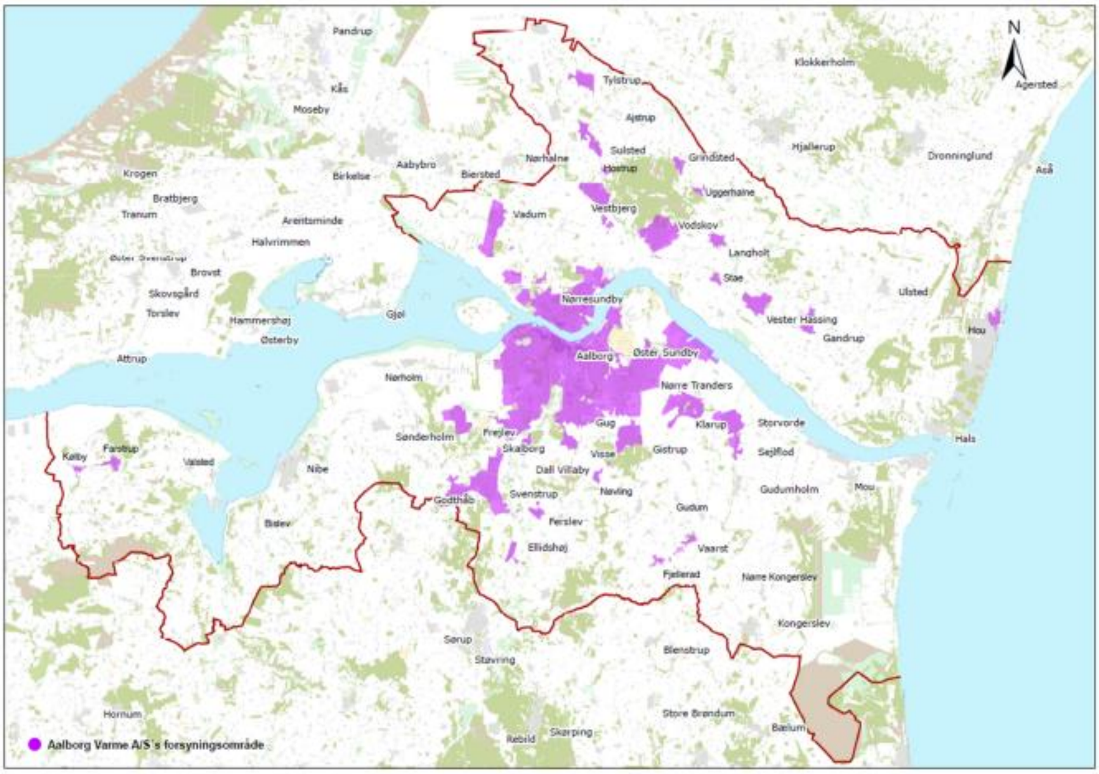

Figure 4. Map of Aalborg Forsyning supply area of district heating (Aalborg Forsyning, 2021a)

Aalborg's network is supplied though a coal-fired CHP (500 MW), waste heat from a cement factory (a baseload of 100 MW) and an incineration plant (70 MW), which represent around 98% of the heat supply. Additionally, 12 heat substations fuelled by gas, 15 small heat suppliers from sewage heat and some small industries cover the rest of the demand. The consumers of the DH in Strovorde are households, with around 400 connections to the network.

There is a possibility to integrate new heat sources to cover future heat demand and to phase out the coal-fired CHP by 2029. The share of waste heat as a heat source is planned to increase from the current 20% to 50%. This will come from different heat suppliers. Another possibility is to integrate heat pumps. Geothermal has also been investigated, but was found to be too expensive. These possibilities to integrate new heat sources contribute to the goals of CO_2 emissions reduction established by Aalborg's municipality (the only shareholder of the DH company). The ownership of Aalborg's DH is public, through the company Aalborg Forsyning, which is owned by the municipality.

When Aalborg Forsyning expands to surrounding cities or areas, either they overtake existing DH networks, extend their existing network or establish new DH networks. Historically, the DH network in Aalborg was established in the city centre. Since the late 1970s it has been expanding to surrounding areas. The main driver of expansion is the strong history in Denmark of securing the most beneficial heat. The Heat Supply Act made it mandatory for municipalities to make a long-term plan to secure the most cost-efficient and environmentally friendly option of heating. Another driver is a process in Aalborg that started in 2005. A more local oriented focus enhanced good relationships with local politicians and other stakeholders.

District heating in Aalborg is among the cheapest in Denmark. Aalborg Forsyning wants to expand it to surrounding areas. For areas with existing DH, Aalborg Forsyning has taken over the networks. Legislation has become more strict and complex. For many of these smaller DH networks, it is easier to transfer responsibilities to larger companies like Aalborg Forsyning, which has the experience and human resources to handle the regulation. You need a certain scale of organisation to deal with the complexity of legislation.

The goal of the municipality of Aalborg is to provide as many households and buildings in the area with DH. Previously they had the option to make it an obligation to connect to the DH system, e.g. in new building areas. Since 2019, the municipality no longer has this option. This can make it harder to have a good business case as Aalborg Forsyning is not assured of a market. Consequently, Aalborg Forsyning has to be competitive in prices. Part of the competition comes from heat pumps. There is a national subsidy for heat pumps. Until now DH has been cheap in Aalborg, due to the waste heat, so DH does offer competitive prices. However, this could change in future, for example due to the subsidy on heat pumps.

Aalborg Forsyning sees transparent planning as key for effective urban planning. In 2010 they launched a plan and extensively communicated about this plan for 10 years. As a result, citizens and potential customers know when to expect DH to reach their area. This is important, because investments in individual solutions are expensive. It is problematic when you introduce DH while customers have just invested in individual solutions. To prevent this, transparency and communication are key. Another benefit is the percentage of houses that need to be contracted before construction starts. Aalborg Forsyning can start with a low entry level of about 50%. Because citizens know that DH is coming, due to the transparent communication, they are willing to contract. As a result, the entry level is less of a problem for the business case.

Aalborg Forsyning has a strategic way of planning and connecting areas. Consider an area which has apartment buildings and standalone buildings connected to gas. The area is split into parts. In the first part, with the apartment buildings, there is only one owner. For this part it is possible to connect 100% of the apartments. For the second part, only a small number of the houses has to be connected, because the apartment buildings are already connected. In this way, the apartment buildings act as a driver to connect the total area. Again, it also has a positive effect on the entry level.

Climate goals have been on the agenda of the municipality of Aalborg since the 1980s. The 2030 goal in their most recent Climate Action Plan is 70% reduction of CO_2 emissions compared to 1990. The municipality has a monitoring role when Aalborg Forsyning wants to connect a new area. Aalborg Forsyning has to calculate the socioeconomic effects and communicate which parties are involved. They communicate this to the municipality, such that they get a good overview of the project. The municipality has to ensure that the socioeconomics are feasible. Next, they are obligated to have a public hearing with parties that are affected by the project. For example, for a project where houses which are connected to gas are converted to district heating, there have to be hearings for the gas company. After the hearing the municipality can approve the project. Finally, there is a period where parties can complain about the decision of the municipality at a national organisation. These are the parties which are also involved during the hearings. After this period Aalborg Forsyning can start the project.

This process before the project can start also has an effect on the competition with heat pumps. For heat pumps there is not such a process in which it has to prove it is the best socioeconomic solution for a district. Municipalities have suggested to have a period for DH companies to explore if DH is feasible. During this period citizens cannot get a subsidy for heat pumps in this area. If the DH company finds it is feasible, then they can continue the DH process. If not, then citizens can get subsidies for heat pumps.

The municipality has indicated that it is important to have clear communication between the municipality and the district heating company. This should be done at the very first stage of the project. They indicate that this is import to align their interests and goals and makes the process easier. Furthermore, the municipality can be clear about what the process is and Aalborg Forsyning can take this into account. The municipality has also indicated that for these projects a lot of approvals have to be given by the municipality. They are trying to make this process smoother.

Regarding the construction stage: innovation is a continuous process. Over the years Aalborg Forsyning has been using better insulation to improve pipe efficiency. Currently, the most efficient pipes with the best insulation values are used. An issue for Aalborg Forsyning is pushing down the temperature. This is a more efficient way of increasing the efficiency than using better pipes. The best pipe technology yields a 1-2% heat loss reduction. Lowering the temperature by 5 degrees results in a 5-10% heat loss reduction. Currently, the temperature in the networks is 60-65 degrees. It can be difficult to maintain a low return temperature. The difference in flow and return temperature is essential for the capacity in the pipes. So if the supply temperature is lower, then the return temperature needs to be lower as well. To monitor this, Aalborg Forsyning has changed all the heat meters for the customers. With these meters Aalborg Forsyning can approach customers who have a problem with the installation and as a result can increase the efficiency of the DH network.

To minimise disruption during construction Aalborg Forsyning only does construction that causes a lot of disruption outside the winter period. Furthermore, they try to finish work within one day. If this is not possible, then they supply people with other means. In Denmark it is mandatory to co-ordinate with utilities to avoid a lot of excavation. When one company decides to operate in an area, Aalborg Forsyning has to join, or cannot enter that area for 5-10 years. This minimises disruption as well.

The tariffs in Denmark are cost-based through regulation. The Heat Supply Act states that costs can be included in the tariffs. There is some freedom for Aalborg Forsyning with tariff structures. For customers with a large heat demand Aalborg Forsyning has a monthly fee instead of a yearly fee. This is a driver to save energy in the cold months, so these customers invest in e.g. insulation. Aalborg Forsyning has indicated that it is important to keep tariffs and regulation simple. Customers used to pay five different fees based on e.g. the size of the house and the pipe. This was changed to only one fee. The first method was more correct, but difficult to explain to customers. Another service that Aalborg Forsyning offers its customers is leasing. Usually when customers have to make an investment when they are connected to DH. This can be a barrier. Leasing takes away this barrier.

4.1.4 Identified best practices

Extracted best practices for the case based on the interviews are summarised below. Practices in **bold** were emphasised by the interviewees during the interviews and can therefore be regarded as being most important for this particular case. Practices in ***bold Italic*** are recommendations for best practices that can be considered as possible improvement or attention points for future projects.

Planning – Business case and costs

- Organic growth of the network.

Planning - Governance

- Having a certain scale of organisation to deal with the complexity of legislation.

Planning – Social acceptance

- **Involve customers as early as possible.**
- Remove the investment barriers for customers, e.g. by the possibility to lease the heat delivery set.

Planning - Regulation, policy and subsidy

- Keep regulation and tariffs simple and understandable.
- Municipalities have suggested having a period for DH companies to explore if DH is feasible. During this period citizens cannot get a subsidy for heat pumps in this area. If the DH company finds it is feasible, then they can continue the DH process. If not, then citizens can get subsidies for heat pumps.
- ***Have a smooth process for approvals from the municipality.***

Planning – Other strategic items

- **Transparent and open process.**
- **Have a pre-dialogue of the project between the municipality and the company: everyone has the same knowledge of the project and interests are aligned.**

Construction - Costs

- Use the best pipe technology available.

- Lower the temperature to increase efficiency.
- Install smart meters to monitor the temperatures.

Construction – Social acceptance

- Co-ordinate with other utilities (mandatory in Denmark), this causes less disruption.
- Only do construction outside the winter period.

4.2 Antwerp

Antwerp is a city in Belgium in the Flanders region. It is the second largest city in Belgium. Antwerp is an interesting project to learn from as the system is based on a large incineration plant that has not used the heat off site until recently. The district heating project starts with a smaller commercial operation from the waste-to-energy company into primarily commercial areas, but with plans to expand into the city and also cover residential areas. The municipality and the DH company had no previous experience with district heating.

4.2.1 Historical and current background

Compared to its neighbouring country the Netherlands, Belgium has significantly fewer DH networks in place. The rate of home ownership is higher in Belgium than the Netherlands, which makes it harder to set up DH networks (RVO, 2019). In 2015, DH delivered roughly 3% of the total heat demand (Heat Roadmap Europe, 2017). While the exact shares of heat sources for DH are unknown, renewable sources amount to a share of 7.8% of heat sources used (European Commission, 2016). Although Belgium has almost no historical DH development, the interest and awareness is increasing. Currently, the majority of the 58 DH networks in Flanders consist of networks supplied by gas boilers or incineration facilities (Vlaams Energie- & Klimaatagentschap, 2021).

4.2.2 Regulatory Framework

Belgium consists of three regions: Flanders, Wallonia and the Brussels-Capital Region. While there is a federal government, regions have a certain level of autonomy when it comes to regulation. The Flemish government implemented a regulatory framework for DH networks in the Energiedecreet. According to this, the Flemish Regulator of the Electricity and Gas Market (VREG) is assigned the task of monitoring and regulating the heat supply market. The VREG monitors the quality, reliability, and operation of DH networks. In addition, the VREG ensures that DH network managers and heat suppliers act in accordance with regulations stated in the Energiedecreet (VREG, 2020).

To promote investment in DH projects, the Flemish government introduced the “Call for green heat, residual heat and heating networks” programme. Yearly budgets are made available for heat suppliers and DH networks to apply for. A condition to access the subsidy is that at least 50% of the supplied heat should be renewable heat, waste heat, or a combination of both. In spring 2021, EUR 12 million was available, with a maximum of EUR 2 million per project (Agentschap innoveren & ondernemen, 2021).

4.2.3 Case study / interview

In May 2020, the incineration company ISVAG in Wilrijk, a district belonging to Antwerp, started delivering up to 3 MW of heat to a nearby business park through a newly constructed DH network with 1.6 km length of pipe infrastructure. In future, the incineration plant can output 50-55 MW of heat and the network might be expanded to deliver heat for 40 000 households in Antwerp.

ISVAG is situated at a business park, Terbekehof, for which renovation plans were being made by the POM (Provinciale Ontwikkelingsmaatschappij). Each Flemish province has a POM, which implements the socioeconomic policies of the provincial government. The POM Antwerpen engages with the development of business parks. They almost never develop new business parks, instead they modernise existing business parks. A lot of the business parks are from the 1970s and have certain issues. For Terbekehof there were issues with the sewage system. As excavations were started for this, it was beneficial to combine it with the construction of DH. The planning of the construction was split into phases, such that the planning of the other stakeholders was taken into account. ISVAG can become part of a large network in Antwerp. First, parts of this network will be constructed, together with other excavation activities. These parts will be connected later. Sometimes these parts will be built with overcapacity, to make the system futureproof. Future expansions are already taken into account.

The POM stresses that it is important that policy that guides development has to contribute to district heating. In Flanders it is forbidden in certain cases to build a gas network. This has a positive effect for district heating. It can also mean that less subsidy is necessary.

Another reason ISVAG decided to plan a DH network is the interest of industry to move away from gas consumption to more sustainable energy carriers. For the planning of the construction of the network, expertise from existing Danish DH networks was used.

Currently, the ownership of the network belongs to ISVAG. However, if the network should be expanded, ISVAG will not be operating the larger network as it does not have the ambition to become a heat company. There are no concrete plans for the network´s takeover soon.

To finance the project, subsidies from the "Call for green heat, residual heat and heating networks" programme were used for construction works carried out in public areas, such as municipal roads. These subsidies were used for the capital costs and covered 85% of this public area's construction works. The tariff for the heat supplied is unknown, but it is comparable to the costs of the former heat supply option. The tariffs are not under the control of the VREG as the DH network only supplies to industry.

Construction works were done simultaneously with other construction works, specifically with the renovation of the sewage system, which reduced costs and made construction easier, while also reducing disruption. To reduce disruption further, they made sure that companies and houses were reachable. Furthermore, sometimes work was done in the weekend, e.g. asphalt construction. In order to support the long-term strategy of the expansion of the network, heat pipes with overcapacity have been installed to be able to satisfy a high demand in the future.

During construction there was an issue with soil contamination. However, during the urban planning phase detailed agreements were made to divide possible extra costs. Per expense an allocation was made, such that it was clear which party would pay for which extra costs. These clear and detailed agreements ensured that construction did not have to stop when an issue such as soil contamination arose. The POM noted that more geotechnical testing could have been done to guarantee the quality of the soil. It is important to have a right balance between the reduction of risk and the costs of testing.

4.2.4 Identified success factors

Extracted best practices for the case based on the interviews are summarised below. Practices in **bold** are emphasised by the interviewees during the interviews and can therefore be regarded as being most important for this particular case. Practices in ***bold Italic*** are recommendations for best practices which can be considered as possible improvement or attention points for future projects.

Planning – Business case and costs

- Build with overcapacity (infrastructure), investment to let the DH grow.
- Customers with a large demand can make your business case profitable.
- Work together with other utilities that have excavation activities.
- Adjust the planning of DH to that of other utilities, work in phases.
- Take time to make clear (and detailed) agreements, especially on risks so you avoid dealing with responsibilities of problems during construction.

Planning – Regulation, policy and subsidy

- Policy should have a guiding role, e.g. not allowing new gas will make DH more interesting.

Planning – Other strategic items

- **When you lack knowledge or experience, collaborate with (international) partners who do have this knowledge and experience.**

Construction – Costs

- Work together with other utilities
- ***Have a right balance between testing and risks, e.g. geotechnical quality of the ground***

4.3 Salaspils, Latvia

Latvia has a good example of a modern and efficient solar district heating plant, built in less than six months. It is the largest solar thermal district heating plant in the EU outside Denmark. The Salaspils case has had district heating for many years and constantly aims at expanding and improving. Here they include a new heat source.

4.3.1 Historical and current background

Historically, DH has developed extensively in Latvia, with its first DH network implementation in 1952. Currently, approximately 600 000 citizens are served by DH (EuroHeat, 2019), which is around 30% of the inhabitants.

In Latvia more than half of the primary energy consumption is used for heating (Energy Post EU, 2021). The most widely used resources for heating in the country (also non-DH) are gas, wood chips, pellets and firewood. Of these, one of the main competitors to renewable heating is gas – used in boiler houses and individual heating systems. According to the Ministry of Economics, 70% of the country's heat is produced in centralised systems, which suffer from ageing infrastructure, inefficiency (high heat losses), and lack of renewable heat sources (Bankwatch, 2021). Historically the main heat source used for DH is CHP plants, mainly on gas; in 2019 this source provided 73% of DH (EuroHeat, 2019).

Most of the DH networks are located in Riga and in eight other large Latvian cities, where population density is high. There are also a lot of small DH systems in smaller towns and municipalities. These systems usually have higher heat losses causing higher tariffs for consumers. As a result, consumers tend to disconnect and arrange their own heat supply which leads to phasing out of these networks (EuroHeat, 2019).

Some of the (large) DH networks in Latvia have been expanded and modernised during the last decades. In the last 20 years, with the support of EU funds, the country has expanded and renewed its district heating networks to improve efficiency, and also switched from gas to biomass- (wood-) based DH systems (Energy Post EU, 2021). There are substantial wood resources available in the country and a thriving forest industry. However, long-term sustainable use of biomass (and filtering of dust in biomass boilers) is of major importance. Therefore, aside from mainly transitioning to biomass, the country is now also considering other innovative solutions such as solar thermal. Solar technologies have recently become more widespread and competitive, lowering their price (Bankwatch, 2021).

4.3.2 Regulatory framework

Improving the energy efficiency of DH networks and promoting the use of renewable energy sources in DH is an important pillar in Latvia's National Energy and Climate Plan 2021-2030 (LV NECP, 2018). Despite this the DH sector does not have a dedicated strategy or plan where specific targets are set (Euroheat, 2019).

In the National Energy and Climate Plan emphasis is put on the energy efficiencies at which the DH networks operate. In Latvia, minimum energy efficiency requirements (average annual) for DH production technologies and maximum losses for DH networks are in force since 2014 (Odyssee-Mure, 2021). Additionally, integration of more renewable energy sources in DH networks is getting attention. The EU Structural Funds and EU Cohesion Fund – consisting of investment grants – were available during 2014-2020 to modernise the networks. This means to increase the amount of renewable energy supply, to expand the DH networks and to improve the efficiency of boilers and the networks (LV NECP, 2018; Odyssee-Mure, 2021). A substantial share of EU funding was and is invested in modernisation of the DH networks, leading to a series of tenders for renewable heat sources and measures to improve the efficiency of DH systems, which started in 2009 (EuroHeat, 2019). The goal for the EU funds given in 2014-2020 was to achieve a share of renewable energy in DH of at least 60% (LV NECP, 2018). Implementation of the funded projects has to be finished in 2023. The co-financing, provided by the Cohesion Fund, is EUR 49.6 million (for total investments around EUR 124 million) (Odyssee-Mure 2021). It is expected that 25% of total investment will be in increasing energy efficiency of DH pipeline networks, 5% to extend DH networks and connect new consumers and 70% to add more RES to DH networks (Odyssee-Mure 2021).

District heating is included in the regulatory framework (Energy Law Latvia, 2021). An important aspect of the law is a tax on natural resources in the country – the more pollution is produced by a source; the more taxes have to be paid. Solar energy is therefore the best solution taxwise, because nothing has to be burned during exploitation.

While large DH networks are regulated on the market, small DH networks are not to prevent additional administrative tasks which would increase the costs and tariffs of the network. The service of thermal energy supply is regulated if the total amount of thermal energy exceeds 5 000 MWh/year. In total, 93% of the energy supplied by DH networks is regulated (Salaspils Siltums, 2021a). The DH company proposes a consumer tariff for a specific DH network based on all expenses, as stated in the Latvian Energy Law, after which the Public Utilities Commission carries out an examination and analyses whether the calculated tariff is adequate. The tariff calculation is made public, so that anyone has the opportunity to get acquainted with the draft tariff until it is approved. The tariff is set up for the thermal unit EUR/MWh. The tariff includes both variable costs (fuel, electricity, etc.) and fixed costs (salaries, depreciation of fixed assets), as well as connection costs in proportion to the planned connections (Municipality of Salaspils, 2021). When planning a project, it is important to roughly calculate the tariff beforehand and to reduce it after the implementation of the project if it was too high. Salaspils Siltums did that – the tariff dropped by 12.7% after implementation (Municipality of Salaspils, 2021).

There is no regulation that obliges consumers to connect (or stay connected) to a DH network. Citizens may therefore opt to switch to individual gas boilers if so desired.

4.3.3 Case study / interview

The main objective of the project was to increase the share of renewable energy sources of the existing network, which was realised by adding biomass (wood chips) boilers and a solar thermal field.

Salaspils is the 11th biggest city in Latvia with more than 18 000 residents and is located 18 km from Riga, the capital city of Latvia. About 85% of citizens in Salaspils make use of the district heating network. There are 172 connections and annual heat supply is about 57 GWh. Of that heat supply, 75% is for the residential sector and 25% for other sectors (state-financed institutions, municipality buildings and commercial) (Salaspils Siltums, 2021a). Figure 5 shows the network layout.

Figure 5. Network layout Salaspils (Salaspils Siltums, 2021c)

The thermal network of "Salaspils Siltums Ltd." consists of a power plant and a ~22 km long heating grid. The flow temperature is 90-60°C, and return temperature is 60-35°C. The power plant consists of three gas boilers (10 MW, 10 MW and 3 MW), two wood chip boiler houses (7 MW + 1.68 MW flue gas condenser and 3 MW + 0.5 MW flue gas condenser) and a solar collector field (Figure 6) with active area of around 22 000 m^2 and thermal energy storage tank with total volume of 8 000 m^3.

Salaspils Siltums supplies all thermal energy demand to their end users. All of the heating grid in Salaspils is owned by Salaspils Siltums Ltd., and are both operated and maintained by the company. Salaspils Siltums is a 100% owned capital company for the municipality. Salaspils Siltums is a self-sufficient company that is able to plan and finance its own projects.

Back in 2012, the heat sources consisted of heat from gas-fired boilers and heat purchased from cogeneration. At a later stage (2017, 2018) biomass was added to the mix replacing gas. Biomass boilers are currently used for the majority of heat demand. The system is backed up by gas boilers that only run when necessary, for example during peak demand and maintenance hours. A large solar collector field was designed and built in 2019 by a consortium of two companies: Filter (Latvia) and Arcon-Sunmark (Denmark) (Municipality of Salaspils, 2021). An experienced building supervisor was associated with the project, who, along with specialists from "Salaspils Siltums", monitored the construction to match the design.

The planned structure of produced heat for the network is that solar thermal combined with biomass reaches a share up to 90%. In summer solar thermal is used as the main heat source. In winter biomass boilers are used as the main heat source.

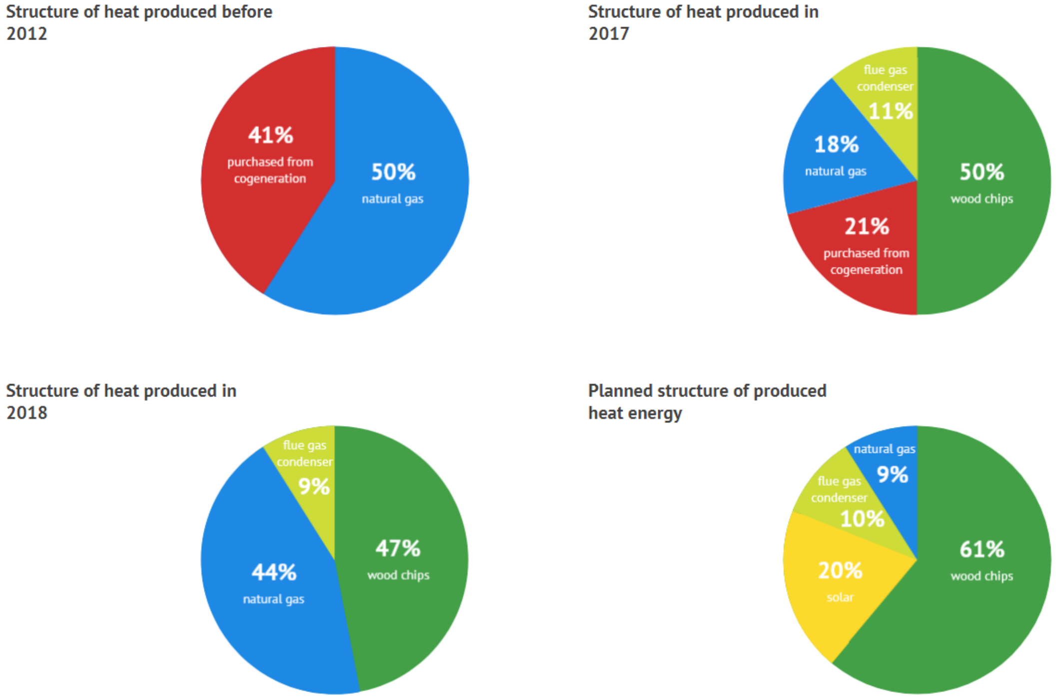

Figure 6. Structure of heat produced for network Salaspils (Salaspils Siltums, 2021b).

In the last 10 years, the amount of CO_2 emissions for heat production has decreased ten times. The amount of CO_2 emitted per unit of heat supplied is 0.019 tCO_2/MWh (biomass is considered CO_2 neutral in the calculation).

Overall the main difficulties in the planning and construction phase of the solar field were due to the lack of experience of local experts in carrying out such projects, which made it necessary to co-operate with geographically remote experts. This project is the largest of its kind in the EU outside Denmark, so Danish experts were the most common assistants and consultants. Latvian and Danish companies worked in close co-operation on this project.

The solar collectors and storage tank were integrated into the existing system during the period 2018-2020. It took 1.5 years to realise this part of the system in which one year was for planning and half a year was for construction. The planning began with a solar potential analysis for the location. It turned out there was plenty of potential to start with. The next step was to search for an empty plot of land in the vicinity. The land was borrowed from the municipality. Construction initiated a while after the land was prepared, which took more time than expected (initially field mitigation was not planned). The last step was to integrate solar thermal with thermal energy storage into the existing DH system.

During planning the heating company shared information about the project on social media to keep citizens involved. They also informed citizens about energy and climate issues. Besides this the company performed a series of public consultations. This helped to increase social acceptance. A survey conducted in 2018 showed a large support base for solar thermal (85%), and also but to a lesser extent (57%) for biomass (Bankwatch, 2021).

Useful routines applied during the construction phase in this project were weekly construction meetings and performance tests as the field of solar collectors in a certain period of time must produce an agreed quantity heat. During construction, the company also recommends (for future projects) to opt for a quality construction supervision company.

Based on the experience of the heating company, they would recommend for future projects that in the planning phase of the heat source (e.g solar collectors) a detailed procurement procedure be prepared by the heating company, where specifically relevant parameters and energy efficiency (performance) requirements are defined, as well as a 6-year warranty. In the requirements it has to be defined that solar collector suppliers must have experience of at least 20 years, as the lifetime of solar collectors is more than 30 years.

Funding of the solar collectors, accumulation tank and a 3 MW biomass boiler and flue gas condenser consisted 40% of an EU cohesion fund, 35% bank loan, and 25% equity capital.

In Latvia thermal energy tariffs vary from about 35 to 70 EUR/MWh, depending on the network. The network of Salaspils is regulated, it charges one tariff (i.e. 48 EUR/MWh) for all the consumers. This tariff is stable and does not change every month.

Diversifying the heat sources and fuels helps this DH network to ensure security of supply during all months of the year and at the same time makes it more flexible (future proof) in its heat supply. Successful integration of renewable sources into the existing system posed system design challenges in the beginning, which seem to be mostly solved now. The right quantity and quality (temperature level) of heat has to be supplied to customers – either directly or from the accumulation tank. In order to (successfully) introduce new technologies into an existing system, the heating company emphasised the need to have an orderly system – in first place the highest boiler efficiency has to be achieved and grid losses have to be reduced. This has been an attention point both in construction and in operation. Flue gas condensers are an important component in the design and they need to be optimised to recover as much waste heat as possible. Periodically, hydraulic tests are performed to identify the bottlenecks and possible leaks in the DH network, to minimise heat losses and to make transmission as efficient as possible. The return temperature has to be lowered (as low as possible) to achieve a higher efficiency. The above ground steel storage tank allows the system to store thermal energy and use it when it is needed, and not when it is produced. The main benefit of storage is the possibility to meet a higher demand with the existing resources, and not rely on new heat sources, because previously stored energy can be used.

Figure 7. Solar collector field for network Salaspils (Bankwatch, 2019/Photo by Kaspars Suskevics, CC-BY-NC-ND)

4.3.4 Identified success factors

Extracted best practices for the case based on the interviews are summarised below. Practices in **bold** were emphasised by the interviewees during the interviews and can therefore be regarded as being most important for this particular case. Practices in ***bold Italic*** are recommendations for best practices that can be considered as possible improvement or attention points for future projects.

Planning – Business case and costs

- **Take your time to make a proper integrated system design.**
- **Plan for a well-structured system (achieve highest boiler efficiencies, minimise heat losses) to be able to introduce new technologies into an existing system.**
- Use thermal energy storage. In this case the thermal energy storage tank is accelerating the payback time. The main benefit of that is the possibility to not use other heat resources, when the demand grows, previously stored energy can be used.

Planning – Social acceptance

- Inform local people on energy issues.
- Perform public assessments and involve citizens.

Planning – Other strategic items

- **Learn about technology from others. If there are no local experts look internationally.**
- **Become more flexible (future proof) in heat supply by diversifying the heat sources and fuels.**
- Focus on locally available renewable energy sources. Conduct a local solar thermal potential analysis. Solar thermal is possible in colder climates (even in climates where it can be -25ºC in winter). This project shows it is possible to run a large solar thermal field without much problem in an integrated DH system.
- ***Use a detailed procurement procedure with performance criteria.***
- ***Involve only highly experienced contractors and installers.***
- ***If lacking expertise, involve a partner with the expertise from the beginning.***

Planning - Regulation, policy and subsidy

- **Use support funds (such as EU cohesion fund) to finance projects in relatively low income countries.**
- Use tariff regulation to provide stable tariffs to customers.

Construction – Business case and costs

- **Weekly construction co-ordination meetings.**
- **Performance tests heat sources, as the field of solar collectors in a certain period of time must produce an agreed quantity of heat.**
- **Involve a wide range of professionals to seek solutions to technical issues of the DH system integration.**
- **Choose a quality construction supervision company.**

4.4 Drechtsteden

Drechtsteden is a region in the province Zuid-Holland in the Netherlands. It consists of several municipalities, one of which is Dordrecht. This district heating project actually is part of a series of thermal networks that is steadily growing toward one larger district heating system. Besides, various renewable heat sources e.g. geothermal doublets and aquathermal energy are becoming part of the extension of this network. The project was also chosen as it presents best practices from creating a project from a group of municipalities.

4.4.1 Historical and current background

The first DH network in the Netherlands was implemented in Utrecht in 1923 (Schepers and van Valkengoed, 2009). Large DH networks (that deliver more than 0.15 PJ annually) are mainly found in a few large cities: Amsterdam, Rotterdam, Utrecht and the Hague, and in a number of smaller cities. In 2018 there were 329 000 connections and 20.4 PJ of heat was delivered. Small DH networks had 64 000 connections and delivered 2.4 PJ of heat. The largest share (over 50%) of this heat goes to households, 15-20% goes to agriculture and 25-30% goes to services (Segers et al., 2019).

There are three main types of heat source for large DH networks: gas and coal, municipal waste and biomass. Gas and coal account for 62% of the heat delivered to large DH networks. 30% of the heat is renewable.

The most established heating technology in the Netherlands is the residential gas boiler. 84% of residences use this heating technology. By comparison, district heating accounts for 6% (CBS, 2021).

The Climate Agreement (a set of measures made by the Dutch government in 2019 to reduce Dutch CO_2 emissions) states that 7 million homes and 1 million buildings will be disconnected from gas by 2050. As a first step, 1.5 million existing homes will be made sustainable in 2030 (Klimaatakkoord, 2019). According to the draft Climate Agreement, municipalities are the directors of the heat transition for the built environment. Together with property owners, residents, network operators and local authorities, they must have a *Transitievisie warmte* (heat transition vision) ready by the end of 2021 (RVO, 2021d). With the *Transitivisie*, municipalities provide insight into the timeline: when can which districts or neighbourhoods be disconnected from gas. For the districts or neighbourhoods planned for 2030, the municipality will also announce the possible heat alternatives (VNG, 2021).

4.4.2 Regulatory framework

In the Netherlands district heating is regulated by the *Warmtewet* (Heat Act) (Overheid, 2020). It has been in effect since 2013 and regulates multiple items concerning district heating, of which the most important is the tariffs. The tariffs are regulated through a gas reference price: district heating tariffs may on average not exceed that of similar heat generation using residential gas boilers. The ACM (Netherlands Authority for Consumers and Markets) enforces the *Warmtewet* and calculates the maximum tariffs.

A new regulation is in the making, the *Wet Collectieve Warmte* (WCW, Collective heat law). In the WCW the tariffs will become cost based.

Additionally, there is legislation that outlines the requirements of the installation and operation of technologies utilised in DH. These are the *Wijzigingsbesluit bodemenergiesystemen* (ECW, 2020) and the *Mijnbouwwet* (Bodemplus, n.d.) for depths up to and greater than 500 metres respectively. Another regulation that is relevant for the implementation of DH networks is the *Gaswet*. The *Gaswet* states that new housing is not allowed to be connected to the existing national gas network (RVO, 2020). This could help stimulate the connection to DH networks.

There are several subsidy schemes in place to finance different aspects of the implementation of DH networks. Firstly, there is the *Investeringssubsidie duurzame energie en energiebesparing* (ISDE). The ISDE provides subsidy for homeowners e.g. for the connection of the DH network to their home (RVO, 2021a). Secondly, there is the *Stimuleringsregeling aardgasvrije huurwoningen* (SAH). This subsidy provides housing associations with a grant for connecting to a DH network (RVO, 2020). Thirdly, there is the *Subsidie energiebesparing eigen huis* (SEEH). This subsidy scheme is granted to projects that aim to increase the energy efficiency of the built environment (RVO, 2021c). Finally, there is the *Stimulering duurzame energieproductie en klimaattransitie* (SDE++). This subsidy encompasses various aspects of DH networks. An example is subsidy available for the use of renewable energy sources (for example biomass) in DH networks (RVO, 2021b).

4.4.3 Case study / interview

For the region in question, the organisation HVC is solely responsible for the complete supply chain. All current and planned (but not necessarily future) heat sources are owned and operated by HVC, the infrastructure is owned by HVC and the operation from maintenance to billing is done by HVC.

HVC is a publicly owned company, the only shareholders are municipalities and water authorities. No other type of shareholders is allowed, and HVC only operates within the geographical limits of its shareholders. An individual shareholder selling its shares only gets a symbolic amount for selling their shares, and no dividends are provided.

The region Drechtsteden can be divided into a few areas: existing networks, networks planned or being constructed, and areas in which possibilities are investigated.

The existing network is in the city Dordrecht. Heat is provided by a waste plant of HVC.

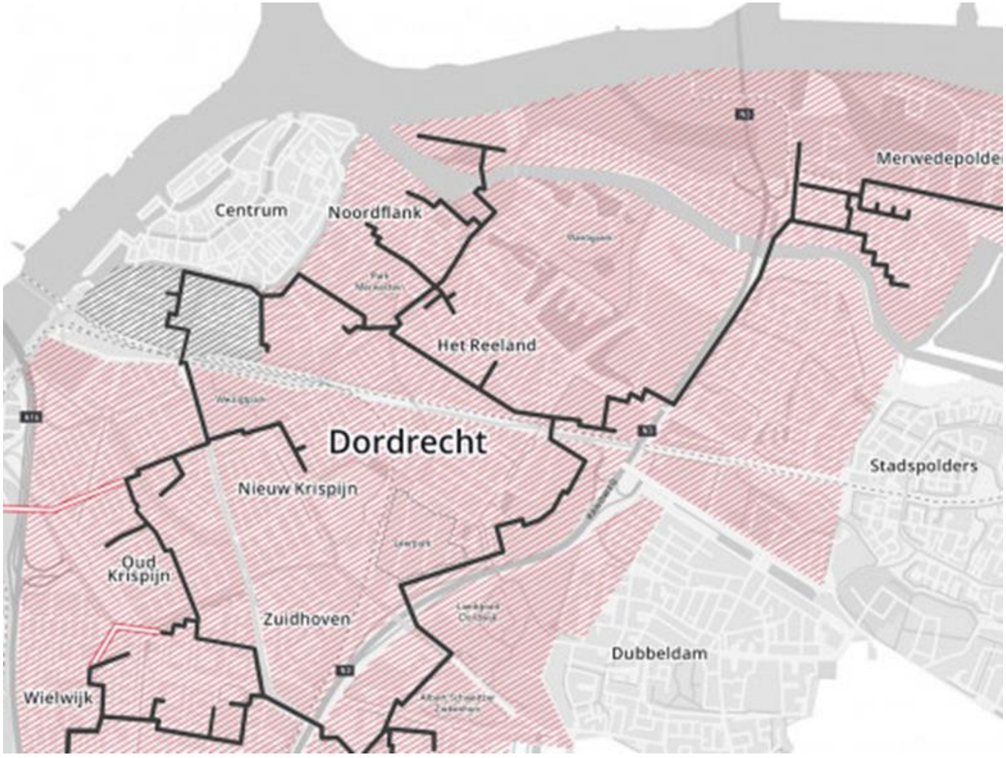

Figure 8. Overview of the primary pipes of the DH grid and the areas to which heat is delivered for the Drechtsteden case (HVC, 2021)

In the small cities Papendrecht and Sliedrecht a limited number of buildings are connected to a temporary gas-based heat installation. Contracts and construction plans are in place in both municipalities to grow towards a network of roughly 5 000 household equivalents in the next five years. Geothermal exploration licenses are owned by HVC and discussions about a potential drilling site are being held with the relevant municipality. Geological research has already been done, both by an internal mining organization of HVC and by contracted specialists. At the same time an alternative is being researched and discussed with the relevant parties: aquathermal energy from a local sewage treatment facility (RWZI). If this option becomes a reality, HVC will do the investments for heat extraction at the site of RWZI. The definitive choice will be made based on a myriad of factors: actual growth of the network, (national) policy, available subsidies, etc.

In the small cities Zwijndrecht and Hendrik-Ido-Ambacht (HiA) a limited number of buildings are already connected to a temporary gas-based heat installation. Construction of an aquathermal plant with the river as the water source will start in the near future. Multiple smaller grids will be developed with the possibility of connecting them in the future depending on further growth. Alternative heat sources research is being done in "average depth" geothermal energy (roughly 1 200 meters of depth). Currently this is being considered as a pilot in a national heat research programme called WarmingUP. Finally, conversations are in place with Gasunie (a Dutch gas infrastructure and transportation company) about the long term possibility to get industrial waste heat from either the Rotterdam region or Moerdijk (which will lead to a supply chain that is fundamentally different in ownership structure than the current one). Neither option seems viable within the next 3-5 years.

In the municipalities Alblasserdam and Hardinxveld-Giessendam, possibilities are being investigated. These municipalities are lighter populated and have no housing corporations with sufficient real estate to create logical and viable short-term starting points for collective heat networks. However, options in the longer term (5+ years) are still being considered and integrated with local policy documents (*Transitiviesie Warmte*).

There is an agreement between the municipality of Drechtsteden and HVC to allow negotiated third-party access. This includes requirements on the location, the availability, the temperature and the pressure. However, currently there are no other heat sources than the ones from HVC. Expectations of non-HVC developed, operated or financed heat sources to be implemented in the near future are limited.

There is no merit order for supplying heat to the network. There are singular heat sources and back-up sources. For the development of new heat sources there is a kind of regional merit order: first local waste and geothermal heat, next is aquathermal energy and finally green gases such as bio and hydrogen. The main logic behind this development merit order is to maximise the use of local low-temperature sources and minimise the use of scarce resources (including electricity).

HVC finances its growth by borrowing at the BNG (Bank Nederlandse Gemeente, Bank Dutch Municipalities). This is made possible because the municipalities guarantee the loan. In exchange they get a guarantee provision of 1%. Additionally HVC recently acquired an additional loan from the EIB (Economisch Instituut voor de Bouw, Economic Institute of Construction). For geothermal projects HVC has used project financing in the past, and this remains an option if and when investments are made in geothermal activities in the Drechtsteden.

HVC and its partners start the DH project with larger buildings like high-rise (flats), hospitals, schools and shopping areas, and to a lesser extent terraced houses (tenants) as it is easier to make an attractive business case for these customers. At a later stage other houses might be connected to the thermal network. Furthermore on the business case: it is important to visualise it from the start, including what a change of conditions will do. This creates insight into the possible risks and benefits. As there are multiple stakeholders in the construction of a district heating network, a clear risk and responsibility package should be created from the beginning.

In the Netherlands, gas is currently the main source for heating through residential gas boilers. It is a long term process to leave gas. That is why it is important to have a phased roll-out. The total process from first meeting to full operation might take up to ten years. For this project a bit more than a year passed between the first idea and the approval of the plan. There were three large meetings involving many stakeholders organised at different levels in parallel i.e. technical experts, project and asset managers, and board members. In between these meetings maps and calculations were made. These roadmap sessions were key to success as they addressed all concerns of the stakeholders and helped create trust and understanding between the stakeholders.

HVC mentions that it is important to create concrete deadlines, both in the urban planning and in the construction phase. Consequently, one might not reach the perfect or optimal solution. One should aim for what is possible. Together with these concrete deadlines goes a time plan of five years for which contracts and agreements should be made. Co-operation with the stakeholders should be based on a joint ambition during a 30-year period.

For the social acceptance it is important to communicate prior, during and after project execution with local stakeholders. At this stage only large institutional customers have been involved, although meetings with local representatives have been organised as well as town hall meetings to inform the local citizens. HVC uses regional meetings and includes five housing corporations (e.g. via their asset managers), the local water company and the municipality. Customers are not persuaded as HVC and its partners start with the larger buildings. A separate communication group has been established for the communication with local stakeholders. HVC works together with all stakeholders to make buildings ready for district heating, e.g. the housing corporation is investigating investments in insulation to improve the overall business case.

During the urban planning phase it is important to take your time, i.e. be patient as the planning phase takes a long time. Furthermore, get all stakeholders involved as of the beginning and throughout the process. Make sure you have commitment on all levels including the steering group. Organise an open process and discuss progress in working groups (technical, risks, legal, finance, etc.) as well as in the steering/strategic group. About ten people of each organisation had a role in this process in this case, e.g. project managers, sustainability experts, asset managers. This results in relationships built on trust. In this process it was beneficial that the region of Dordrecht and surrounding cities (Drechtsteden) is well organised.

During the construction phase one should be prepared for hiccups. As aforementioned a clear risk and responsibility package made during the planning phase can help with this. As during the planning phase, make and keep deadlines, especially when time-limited support is available. Do not aim at the optimal solution, but the possible solution.

During this project, no one was appointed for all matters regarding “below the ground”. However, the interviewee from HVC would do this in a future project. Further, structural agreements, e.g. polluted soil, should be included in the risk and responsibility package.

Going from the urban planning phase to the planning of construction can be difficult. A solution can be to overlap these phases. Further, a document should be created for the entire process. This will offer an oversight of the process. HVC held co-ordination meetings with stakeholders during construction. These meetings helped create trust among all involved, which makes the construction phase progress easier.

4.4.4 Identified success factors

Extracted best practices for the case based on the interviews are summarised below. Practices in **bold** were emphasised by the interviewees during the interviews and can therefore be regarded as being most important for this particular case. Practices in ***bold Italic*** are recommendations for best practices which can be considered as possible improvement or attention points for future projects.

Planning – Business case and costs

- Start with the larger buildings.
- **Visualise the business case from the start, including what a change in conditions will do.**
- **Have a clear risk and responsibility package from the beginning.**
- **Phased roll-out.**
- **Create a concrete deadline and don’t mind if this will not result in the perfect solution.**

Planning – Governance

- *Define a 30 years ambition with all stakeholders, and then work on a five-year plan.*

Planning – Social acceptance

- **Communication prior, during and after project execution with local stakeholders.**
- **Work with all stakeholders to make buildings ready for DH.**

Planning – Other strategic items

- A transparent process and joint commitment of the stakeholders involved.
- Take your time for the planning phase.
- Create understanding and trust.

Construction – Business case and costs

- Structural agreements e.g. polluted soil.
- *Appoint someone for all matters regarding “below the ground”.*
- **Be prepared for hiccups.**
- **Make and keep deadlines.**
- **Do not aim at the optimal, but the possible solution.**

Construction – Other strategic items

- Co-ordination meetings.
- Create a document for the entire process.

- Make an overlap between planning phase and the planning of construction.
- Create trust among all involved.

4.5 A2A Smart City, Milan

The case of Milan shows how interconnection of separate DH networks can help to optimise and develop the whole system to achieve heat supply from more efficient heat sources (such as waste-to-energy CHP).

4.5.1 Historical and current background

Since 1972, district heating in Italy has been gradually increasing and by 2017 it was covering around 6% of the total residential heating demand. There are around 200 DH systems in Italy (JRC, 2016). Almost all DH networks are located in the north part of the country. Today, Brescia has the largest DH network, followed by Milan and Turin. Most of the DH networks were originally publicly owned. However, more recently the DH systems are mostly privately owned and the three large networks mentioned earlier are governed by public-private partnerships (JRC, 2016). Today A2A Calore e Servizi is the largest Italian operator in district heating (A2A calore e servize, 2021). Other large operators in Italy are IREN, HERA and EGEA.

The heat sources (primary energy mix) used in DH networks are diverse although it consists mainly of gas. The following breakdown can be given for 2014: fossil fuel CHP (50.5%), municipal waste-to-energy plants (16.5%), boilers on fossil fuels (23.6%), boilers on renewable heat sources (6.3%), geothermal (2.7%), heat pumps (0.4%) and no industrial waste heat (JRC, 2016). In 1995 the renewable sources supplied just 3% of the total heat for DH networks (EuroHeat, 2019b), in 2017 this percentage was 24%.

In 2017, waste-to-energy occupies the second place as a heat source used in DH networks (after gas) (EuroHeat, 2019b). Focusing on renewable sources, bioenergy has an important role (in particular biomass) as the third fuel in district heating systems. Even with its large potential, the use of geothermal resources is still marginal. In 2017, in addition to the first solar district heating system in Varese, two other DHC systems integrated solar energy in their mix, in Lodi and in Forlì (EuroHeat, 2019b).

There is no obligation to connect to DH in Italy. Customers can choose their own heat option based on heat prices. The main alternative to DH is the use of gas boilers, which dominate the heating market (JRC, 2016).

In Italy, DH is still perceived by some as a rather old and inefficient technology (JRC, 2016). There is still a large untapped potential to deploying more efficient DH systems in large cities and to integrate more renewable sources and more industrial waste heat and heat from CHP plants in these networks. There is however nearly no policy support for DH from the national government.

4.5.2 Regulatory framework

There is a national heat strategy in Italy and it is contained in the National Energy and Climate Plan. The Italian plan has different targets and starts from EU 2050 objectives. To reach these goals the Italian government incentivises renewable sources and, for the first time, gives great attention to renewable heat sources (EuroHeat, 2019b). DH does not play a key role yet in Italy, but the government has recognised that it can contribute to the objectives. In the National Heat Plan, the government focuses on:

- Review of Italian district heating potential;
- Developing 4th generation DH systems;
- Developing low-temperature DH networks;
- Use of thermal storage;
- Integration of different sources: waste heat, heat pumps, solar, etc.

There is currently not much government support for DH in the form of policies. There are no investment grants for DH (specifically for DH) at the moment. DH does qualify for various tax benefits for heat production at the end user (citizens). For instance, a reduced VAT rate is applied to heat sales to residential consumers supplied with renewable heat sources or CHP in Italy (NEEAP Italy, 2017).

No technical regulation is present at the moment (e.g. minimum technical standards that have to be met by DH systems such as maximum CO_2/kWh, minimum percentage of renewables, maximum losses).

ARERA, the Italian Regulatory Authority for Energy, Networks and Environment has the goal of maintaining a reliable and transparent tariff system. ARERA regulates tariff calculations and protects consumers against high tariffs. It determines the criteria for determining the users fee for connection to the district heating network and the procedures for exercising the right to disconnection (Freni, 2021).

4.5.3 Case study / interview

The first district heating network in Milan was built in the early 1990s. The historical development of Milan's district heating system has been nodal with multiple small networks developed in the city (UNEP, 2015). The networks are depicted in Figure 9. The network consists of five main distribution networks and six minor networks creating individual nodes of district heating. A2A Calore & Servizi is the current heat supplier. One of the large heat sources is located in the west area and is a waste-to-energy plant (Silla 2). A second large heat source is located on the other side of the city centre and is a gas CHP plant (Canavese). The Canavese heat plant is combined with a groundwater heat pump to feed the DH network in the east. Dependent on the relative demands for heat and electricity, the electricity from Canavese can be used to power heat pumps connected to an aquifer under Milan. There are also other heat sources and also storage tanks to store heat. A review of the system in 2006 showed the need for improved efficiency and a cleaner fuel source. Expanding the network is also a way to connect more buildings that are currently individually heated by gas and diesel (oil).

Figure 9. Map of the existing network infrastructure and planned expansion of the district heating network in Milan (Heat Roadmap Europe, 2017)

In 2010, gas and electricity company A2A (A2A is 50% owned by shareholders and 50% by municipality) and the city of Milan initiated a project to interconnect the networks in order to optimise and develop the whole system. Through interconnection it becomes possible to supply more heat from the more efficient plants such as the waste-to-energy CHP. Eventually, the aim is to achieve a ring-shaped network in the city centre that connects all the separate networks. The urban planning began in 2010 and took at least two years. In 2013 and 2014 construction proceeded and took approximately one year. Thanks to the coupling more heat is recovered from the waste-to-energy plant, thereby replacing less efficient plants (e.g. heat only boilers) and lowering CO_2 emissions.

The coupling of the networks was planned and executed in phases. There was an overlap between the planning phase and construction. During planning and construction co-ordination with different municipalities in Milan was needed. There are nine municipalities in total in Milan. The network goes through three municipalities and consists of 12 distinct parts with, according to the operator, no or almost no co-ordination between municipalities. Authorisation for construction was needed for each separate segment, which was a lengthy process according to the operator as so many parties were involved. The different parts of the network were also constructed by different companies.

During the planning phase, the heat company started by looking for potential large customers (i.e. large buildings). The heat company then sent out letters to building administrators to ask them to connect to network. There is no obligation in place to connect existing buildings to the DH network.

It was difficult for the operator to find the best way to install big pipes in small roads. The local police has to approve the execution of the work and that was difficult. There were also some problems with underground parking – the operator needed to change the route to avoid problems when the parking lot was built.

The heating company held construction co-ordination meetings. It can be hard to install big pipes in small roads. To do so the roads need to be closed and traffic disrupted. In Milan the coupling of the small networks was executed in phases. By doing it this way only some streets had to be closed for traffic at the same time. The disruption of traffic was handled separately for each part of the network. The municipality has a major concern about traffic disruption during construction. The disruption of traffic was handled separately for each part of the network. For this A2A had to plan all the construction work and co-ordinate with the police.

In addition while doing construction it was important for the heating company to be prepared for hiccups. For instance, network routing can be difficult because of obstacles in the way.

The municipality was an important stakeholder (partner) through the entire project and was involved in the urban planning and construction phase, mainly to define the routing of the network during the planning phase. The municipality helped overcome DH network routing issues like railways, roadways, waterways, etc. The operator indicated that municipal involvement was essential for the success of the project – they could not build or connect without them. Communication and meeting with the municipalities were crucial. Therefore the municipalities can be regarded as shareholders. They help find ways to overcome problems e.g. routing and co-ordinate plans for routing with them. They also discuss with local police. This is a fundamental point.

The operator used a decision support tool (OPT IT) to assist in their investment decision making process in the planning phase and to decide on the optimal network routing. The tool simulates the heat flows in the network and calculates the business case. The tool helps to optimise the return on investment. This tool was very important in the planning process. It is the first tool like this on the market.[3]

The Milan case showed that there is a lack of awareness of the importance of energy planning – right now the planning takes way too long. Local municipalities have to provide a plan for infrastructure that includes DH. In Milan there is a plan from eight years ago that is outdated. However, the municipality pays no attention to the need for energy planning at the moment (according to an interview with the DH company). The city of Milan is part of the C40 project and has to become CO_2-neutral by 2050.[4] But what that means has not yet been analysed.

A2A also shared some possible improvement points for future projects:

- Keep track of heat losses. Knowledge on heat losses is lacking and is not included enough in business cases and calculations.
- Use the best pipe technology. For the next project more information on insulation is needed. What is the best choice is not on the agenda and that relates to the price of heat.
- Achieve maximum heat recovery of heat generated by incinerators. Aim to utilise this potential fully.
- There is a huge untapped potential (waste-to-energy, biomass, solar thermal) and it could grow much if a subsidy was provided by the government.
- The municipality needs to guide the transition to low-temperature heating systems in houses, thereby helping to prepare houses for low-temperature networks. And thereby also steer towards newer generation DH networks (with lower heat losses).

4.5.4 Identified success factors

Extracted best practices for the case based on the interviews are summarised below. Practices in **bold** were emphasised by the interviewees during the interviews and can therefore be regarded as being most important for this particular case. Practices in ***bold Italic*** are recommendations for best practices that can be considered as possible improvement or attention points for future projects.

[3] More information can be found at www.optit.net/en/innovation/publications.
[4] See www.c40.org/press_releases/25-cities-emissions-neutral-by-2050.

Planning – Business case and costs

- **Phased roll-out of the network**
- **Dialogues between the municipality and DH company about the network routing. Municipality helps to find optimal routing, e.g. to avoid obstacles.**
- Use a decision support tool (e.g. OPT IT) to optimise the business case and decision making (e.g. to optimise the project return on investment).
- ***Keep track of heat losses for the business case. Currently, more knowledge on heat losses is lacking. This should be included in business cases and calculations.***

Planning – Social acceptance

- **Organise meetings and engage with stakeholders**
- ***Support from political level would be helpful to improve the image of DH.*** *The heating company now has to convince the municipal technicians and the police (and citizens) that they do not try to destroy the city because of the environmental (sustainability) benefits. The construction of a DH network creates a big infrastructure hassle for a relatively short time, but in the end there is a piece of infrastructure that lasts for 50 years. People mostly look to the disruptive side.*

Planning – Regulation, policy and subsidy

- ***Regulation, policy (and subsidies) should all be guiding DH development. The operator should receive support from DH policies. The government has certain tasks and responsibilities, e.g. provide a clear policy on transition to district heating, and to facilitate the transition to a lower heat supply temperature in future.***
- ***Keep the municipal authorisation (approval process) as simple as possible.***
- ***There is a large untapped potential for waste-to-energy, biomass, solar thermal for DH in Italy and it could grow much more if a subsidy is provided by the government.***
- ***National and local government still need to refine their national heat strategy, and get support for it****. At the national level there is no supported heat plan (according to the DH company). There is potential for waste heat, heat from biomass, and a bit of solar thermal. Local municipalities have to provide a plan for infrastructure which includes DH. In Milan there is a plan from eight years ago that is outdated. But the municipality pays no attention to the need for energy planning at the moment (according to the DH company). The city of Milan is part of the C40 project and has to become* CO_2 *neutral by 2050. But what that means has not yet been analysed.*

Planning – Other strategic items

- If lacking expertise (e.g. network routing, optimal decision making), involve a partner with the expertise from the beginning.
- Focus on locally available renewable or waste energy sources (these have to be secure, environmental friendly).

Construction - Business case and costs

- **Construction co-ordination meetings.**
- Be prepared for hiccups, e.g. network routing can be difficult because of obstacles in the way.
- ***Use the best pipe technology. For an upcoming project more information is needed on the insulation of pipes - what is the optimal choice?***

Construction – Social acceptance

- **Plan all the construction works and co-ordinate with the police on how to minimise disruption of traffic.**

- Execute project in phases to minimise disruption to normal city life.

Planning – Other strategic items

- Make an overlap between planning phase and construction

4.6 Bruchsal, Südstadt

Bruchsal is a city in the Bundesland (state) Baden-Württemberg in Germany. In Baden-Württemberg a recent heat law requires the 103 largest local authorities to make heat planning. Bruchsal has already done so and implemented a district heating system, and can be seen as a forerunner for the other 102 local authorities. In this case, neither the DH company nor the municipality had any experience in DH.

4.6.1 Historical and current background

In 1900 the first buildings were supplied with electricity and heat in Dresden from one single CHP. This is considered the starting point of the development of district heating in Germany. After the first world war, heat produced directly by fuels became too expensive, so existing CHP systems were expanded to larger scales with new DH networks (Fernwaerme, 2021). After the second world war, DH was a cheap option for the East. For the West, decentralised heating systems were more attractive, as coal and gas were cheaper (Fernwaerme, 2021). Dependence on foreign raw materials was reduced because of the oil crisis in the 1970s, and gas- and coal-fired CHP plants became more important to produce DH (Fernwaerme, 2021). In the 1990s, liberalisation of markets became essential for national energy policy. In 1998 during the revision of the Energy Industry Act, the market was liberalised. Regional monopolies were abolished and every potential provider was free to enter the market. However, companies were still required to provide information on how the prices are set (Fernwaerme, 2021).

Currently, the DH network sector is well developed but the market has shifted back to becoming more state owned. Several private local utilities are now municipalised. These utilities are called Stadtwerke (Fernández et. al., 2016). There are more than 1 400 Stadtwerke, collectively operating with a total installed capacity of almost 50 GW_{th}, which serve more than 12 million citizens in Germany, where the market share of DH in 2019 amounted to 13.8% (Euroheat&Power, 2019). Currently, 41% of total heat production goes to the residential sector, 38% to the industrial sector and 21% to tertiary sectors (Fernández et. al., 2021). Fossil fuels are still the most important heat source for district heating. In 2017, coal and gas supplied 36 and 38% respectively. The amount of renewable heat accounted for 12% of the heat supply, mainly biodegradable waste, biomass and geothermal (Euroheat&Power, 2019).

4.6.2 Regulatory framework

There is little national regulation in Germany. Most regulation is at the level of the Bundesländer (states) and municipalities. There is no price regulation, the supplier of district heating is allowed to set the price. However, they are required to show how prices are determined. Mostly, DH systems are operated by municipal utilities called Stadtwerke. Most of the district heating networks owned by a Stadtwerke do not allow third-party access. The Bundesländer can permit municipalities to have an obligation to connect to district heating for certain areas. About 35% of district heating connections have such an (partial) obligation (IEA, 2020).

The Renewable Heat Act is a national policy related to DH. This act enables sustainable development of heat and cold supply and helped increase the share of renewables to 14% in 2020. It did this by obliging newly constructed buildings, both private and public, to have a share of renewable energy for space heating and cooling and hot water supply (Erneuerbare-energien, 2009). The minimum share depends on the type of renewable that is used, which the owner is free to choose. When DH is applied and at least 50% of heat comes from waste heat or CHP, this criterion is fulfilled (IEA, 2017).

The CHP Act promotes the expansion of DH and installation of CHP plants. This act makes surcharges available for building CHP plants that can be applied to DH, and CHP operators are compensated for higher costs. The electricity grid operators are obliged to connect to these plants and give them prioritisation. The act also includes a premium on top of the spot market price for CHP-produced electricity and a subsidy scheme for municipalities when installing DH (Fernández et. al., 2016).

The introduction of the Building Energy Act aims to make the renewable share of heat sources dominant in monopolised gas-fired CHPs in DH networks (Fernández et. al., 2021).

4.6.3 Case study / interview

The project started when one of the schools in Südstadt had to rebuild its heating system. It is a public school from the Landkreis, which is one administrative level above the city. From the urban development department of the municipality came the idea to ask the school if they could be part of a district heating system, so that existing buildings in the neighbourhood could also participate. In the neighbourhood of the school there are several big apartment buildings. Next, Stadtwerke Bruchsal (the municipal utility company) was included in the project. For them the project was interesting because in the long term they are looking to shift away from gas. Another public school would also have to rebuild their heating system in two years. At that moment the two schools and Stadtwerke Bruchsal sat together to start the project and an offer was made to the houses along the route. During the urban planning phase a residential home for seniors came into the project. They wanted to be connected to the system so the district heating grid had to be extended by about 600 metres and along that line some private owners can also be connected to the system.

There are three categories of houses: houses belonging to a private housing company, houses belonging to a city housing company and houses belonging to individual homeowners. It is most difficult to discuss with the individual homeowners, because they are many and they usually decide based on consensus. For these apartments it is not mandatory to connect to the district heating network. The business case for the DH network works with only the two schools. Every apartment is a bonus but the business case does not rely on them.

The municipality indicates that it is key to consider the energy need of large public buildings such as the public schools in this project. This is not done in a systematic way yet. The facility managers of individual buildings know when their heating systems need to be replaced, but there is no level of urban planning that brings this information together. In a subsequent project, the municipality also started with a school from the Landkreis and saw that a castle, which belongs to the state of Baden-Wurtemberg, and the state prison building are both close to this school. Such an overview of public buildings with a large energy demand can offer many possibilities for district heating. These buildings function as anchor loads to the district heating grid.

Stadtwerke Bruchsal has recommended placing more focus on the aim of the project in the beginning: what do we want to achieve? It is important to have clear goals and targets from the outset.

The choice of heat sources was straightforward. They wanted to use local and renewable sources. The heat load was too high for heat pumps, so instead pellets and wood chips were used as a heat source. Hot water storage was included as well.

The layout of the grid changed during the planning process. It is more a line than a grid. There were alternative routes possible, through green areas or under the pavement. In the end a combination was chosen: 60% of the length is in green field and 40% in existing sidewalk. This sidewalk had to be renewed, so this was combined with the work for district heating. As a result the cost of the pavement could be kept as low as the cost in the green field. Figure 10 shows an overview of the layout.

The lifetime of the DH network is calculated to be 20 to 30 years. However, based on the company's financial planning when calculating the heating price, a longer period of 40 to 50 years is used. The contract lifetime for customers is usually 10 years. Customers can also take an all-in price that already includes the heat exchanger or some small heat storage. This can take away the investment barrier for customers.

Figure 10. Map of the planning of the district heating network in Südstadte, Bruchsal (Stadtwerke Bruchsal, 2021)

As a public company, Stadtwerke Bruchsal has to tender the contracts to determine who will perform the work. At first they tried to have one big tender and they needed a company who was able to do a lot in the entire heating system. The prices of the offers were 30 to 40% higher than the calculated amount. They then split up the tender into 8-10 smaller parts. The costs were much lower than for the one big tender and it allowed smaller specialised companies to participate. However, project management became harder and there is a risk that not every tender gets a reaction. Splitting up the tender into multiple tenders was crucial for this project, because the market was overheated at that time. However, it is not a given success factor in all situations. So, splitting up the tender can be a success factor, given that it is done at the right moment. In this case, it allowed for more competition for the tenders and consequently for lower total costs.

The funding of this project was covered 80% by an environmental programme of the Federal Republic of Germany. This subsidy programme invites all municipalities to send in their projects aimed at reducing greenhouse gas emissions (UNFCC, 2013). There were restrictions for this subsidy: the project had to be ready before 2022, the CO_2 emissions had to be nearly zero, etc. Additional costs were not funded. Different levels of government (national, *Bundesländer*, *Landkreis*, city) had an influence on the project. They all have a specific say in projects. In this project, the *Landkreis* owned most of the ground, so they had to give permits.

A condition of government support was to already involve the population at the urban planning phase. Information meetings with the local population were planned to inform them about what was happening. The residential house owners have to know if they should invest in a new individual heating system or if they can connect to district heating to avoid CO_2 tax. The planning roadmap maps who is interested in connecting to the system. If there are enough in an area, then the grid can be extended.

The municipality has expressed that they could have done more work to inform the people in the neighbourhood of what they were planning and doing, and which opportunities this would offer for people when the system was finished. If they had explained that better and earlier, they expect that more people would have been enthusiastic from the beginning.

During the urban planning phase there were several uncertainties that had to be dealt with. The first school was a protected historic site. Consequently, the design had to be changed in such a way that construction could be done while preserving the school. This was not planned for at the beginning. Another difficulty was the final cost of energy. At the beginning this was unknown, especially because the municipality did not have experience with district heating. However, the information was necessary in order to have the partners sign the contracts. As a result Stadtwerke Bruchsal had to do calculations and estimations earlier than expected at the beginning. They took on external consultancy and engineering companies who did these calculations. This is a learning process that the municipality and Stadtwerke went through, and they expect that this will become easier after a few projects. One partner in the project, an energy agency whose shareholders are three municipal utilities and the district as well as a network company, helped to clarify the strategic and environmental questions in an early phase. They provided help in describing the vision, the benefits of DH and by broadening the view in several stages of discussion. They brought in the engineering companies to help the municipality and Stadtwerke. In future projects they will ensure that an engineering office for heating system is part of the project from the beginning. In future projects they will also determine the amount of heat that is needed in an area earlier in the project to determine whether there is enough demand to know whether DH can be an economical solution.

The state Baden-Württemberg says that every city in the state needs to create a heat plan. In its strategy, Bruchsal specified where the city needs to be in 2050. There is a long-term strategy to add heating systems and connect them with existing systems. It connects local heat sources to anchor customers. This is also a part of the larger heating strategy of the *Landkreis*. At that planning level, it can be interesting to connect in the future to other city systems. These developments are incorporated in the planning and design of current systems: a slight over-dimensioning of pipes is taken into account.

The municipality has mentioned that the social view and the politics around district heating are relevant. Since the 1970s energy crisis in Germany there has been a movement of people who prefer to take care of their own heating system. Only in the large cities has there been a tradition of district heating since the 1970s. District heating is now starting to be accepted in other parts of Germany as well. For those building new housing it is also a solution, because it avoids the need for (large) systems within a building. The political climate also has an influence on a project; it helps the project when politicians support district heating.

The urban planning phase took a long time. It took long, because everyone has different views of the project at the beginning and these have to converge. Most problems should be solved during the planning phase and not when you go into the field and start construction.

As said before, the district heating network went through green fields and sidewalks. Working in green fields minimises the impact on city life. Also the work on the sidewalk did not cause too much disruption, as the rest of the street was still available. Consequently, there was no need to take special action to avoid disruption.

The tender was split up into several tenders during the planning phase. As such, several contractors were involved in the construction phase, e.g. for the grid work, the duct lines, the heating machinery, the silo for wood chips, and a gardening company to cover it all up in the end. Stadtwerke had to do the project management: negotiate with the partners and construction teams. They convinced the partners to put more time in, to create a bond and be partners for the next projects as well.

No innovative methods were used during the construction phase. Instead, proven systems were used to minimise the risks of the project.

4.6.4 Identified success factors

Extracted best practices for the case based on the interviews are summarised below. Practices in **bold** were emphasized by the interviewees during the interviews and can therefore be regarded as being most important for this particular case. Practices in ***bold Italic*** are recommendations for best practices that can be considered as possible improvement or attention points for future projects.

Planning – Business case and costs

- **Focus on locally available renewable energy sources.**
- **Use hot water storage.**
- **Start planning with large consumers.**
- Create an overview of the heat demand in an area in the beginning to determine whether district heating can be an economical solution.
- If the situations asks for it, break up a tender into multiple smaller parts.
- Over-dimension the pipes for future expansions and connecting systems.
- Work together with other projects, e.g. refurbishment of pavement, to reduce costs.

Planning – Governance

- Long-term strategy to add heating systems and connect with existing systems.
- **Have an overview of public buildings with a large energy demand.**

Planning – Social acceptance

- **Plan the pipe routing through green areas to reduce the impact on city life.**
- Offer an all-in price to customers to remove the investment barrier.
- Involve the local population during the planning phase.

Planning – Regulation, policy and subsidy

- Political (and social) climate is relevant, it helps when they support DH.
- A government can add conditions to subsidies to steer towards what they find important, e.g. include local population, low CO_2 emissions, etc.

Planning – Other strategic items

- *Have clear goals and targets from the beginning of the project.*
- Take your time for the planning phase.
- If you lack expertise include a company with this expertise from the beginning.

Construction – Business case and costs

- Use proven systems to minimise the risks of the project.
- Solve problems as much as possible before you start construction.

Construction – Other strategic items

- Put more time in the project to create bonds with partners for future projects.

4.7 Móstoles, Madrid

The case was selected because it is currently the largest DH project in Spain on biomass. This heating company made use of an extensive communication plan aimed at citizens. In this way they spread knowledge about DH benefits, which increased social acceptance.

4.7.1 Historical and current background

In Spain most buildings are heated individually, mainly with gas, but also other fossil fuels such as oil. Around 120 000 citizens were served by DH in 2017 (JRC, 2021). This represents less than 1% of the Spanish heat market in terms of installed capacity in 2017 (JRC, 2021). A low market share for DH can be explained by a relatively low heating demand, lack of awareness and experience in DH of urban planners and the widespread use of gas and other fossil fuels for heating (JRC, 2016). The majority of DH networks emerged after 2000. Most DH networks are found in the Catalonia region. Since 2013, the development of DH systems has increased notably with a strong increase in the total length of the DH networks (Euroheat, 2019c).

The energy mix for DH in Spain consists mainly of gas-fired CHP and biomass. A trend visible in small- and medium-sized municipalities is to choose centralised heat and cold generation over individual heating options as a way to switch to more sustainable heat and cold (Euroheat, 2019c).

One of the objectives of the National Energy and Climate Plan 2021-2030 (NECP) is the development of DH systems and increasing the share of renewables in the heat supply mix (MITECO, 2020). The evaluation of the potential at local level for DH networks in new building areas and the modernisation of the already existing networks are measures included in the NECP.

Municipalities as well as regions play a key role in stimulating DH. Large cities such as Barcelona strongly support DH in urban and energy strategies. In recent years, there has been more awareness-raising in Spain about the benefits that DH could bring, for instance in terms of cost and energy savings, reduction of fossil-fuel dependence and positive impact in the local economy (JRC, 2016).

4.7.2 Regulatory framework

There is no specific district heating law in Spain, but the National Energy Efficiency Action Plan does support the deployment of DH and cooling systems through national funds (JRC, 2016). Financial support is available for various sustainable heat sources such as geothermal and biomass (Baerbel, 2015), as well as for district heating pipes (ERRA, 2011).

District cooling, which has other best practices, is not dealt with further here as the case involves DH.

At national level there is the National Plan of Dwellings 2019-2021, established in the Strategy for Rehabilitation of Energy in the Residential Sector (ERESEE) and the Energy Rehabilitation for Dwellings Programme (PREE). The ERESEE provides funding for the connection of DH networks for households, in which the maximum funding available is between 8 000 and 12 000 EUR/dwelling (MITMA, 2020). The PREE provides funds for those DH networks operating on geothermal energy or biomass (IDEA, 2020). Additionally, there are funds granted on a local level by the Autonomous Communities. These grants are provided from EU funding programmes such as the FEDER (European Regional Development Fund) (ADHC, 2020).

There is no obligation for consumers to connect to DH in Spain.

There is no market (tariff) regulation in Spain (JRC, 2021).

The governance of the DH networks is divided between public (32%), private (35%) and public-private partnerships (33%), based on installed capacity (JRC, 2021). In the public-private partnerships there is co-operation between (local) governments to acquire funding, and the private sector, which brings their expertise.

4.7.3 Case study / interview

The Móstoles DH network is located in a town in the southwest of Madrid (Figure 11) with a population of more than 200 000 inhabitants, and has been operating since 2017. It is a biomass-based DH network and it is the largest DH network on biomass in Spain.

Planning for the project began in 2010-2011. The plan was to phase out existing community boilers in apartment buildings on oil or gas and to replace them with heat from a centralised biomass boiler. The local heating company Móstoles District Heating (DH Eco Energías) – the original owner of the network – spent three or four years looking with the municipality for a good place for the DH network. In 2015, the network construction phase began and in 2017 the biomass plant was inaugurated (Euroheat, 2019d; Energynews, 2017). In 2015 Móstoles DH signed an agreement with Veolia. Veolia now owns 90% of project shares. Veolia constructed the DH network and is the operator of the network. The network design was made by Móstoles District Heating.

The centralised heat plant has a capacity of 12 MW and consists of three biomass boilers fired by wood chips. There are 12 heat exchange substations spread throughout the network, with different capacities, supplying heat to between 30 and 360 customers (Figure 12). Hot water supply is carried out by a closed circuit that reaches the homes at about 90°C and returns to the plant at about 70°C, where the boiler has to raise the temperature by 20°C before sending it back to the homes (Energynews, 2017).

Figure 11. Location of DH network Mostoles, Madrid (Veolia, 2019)

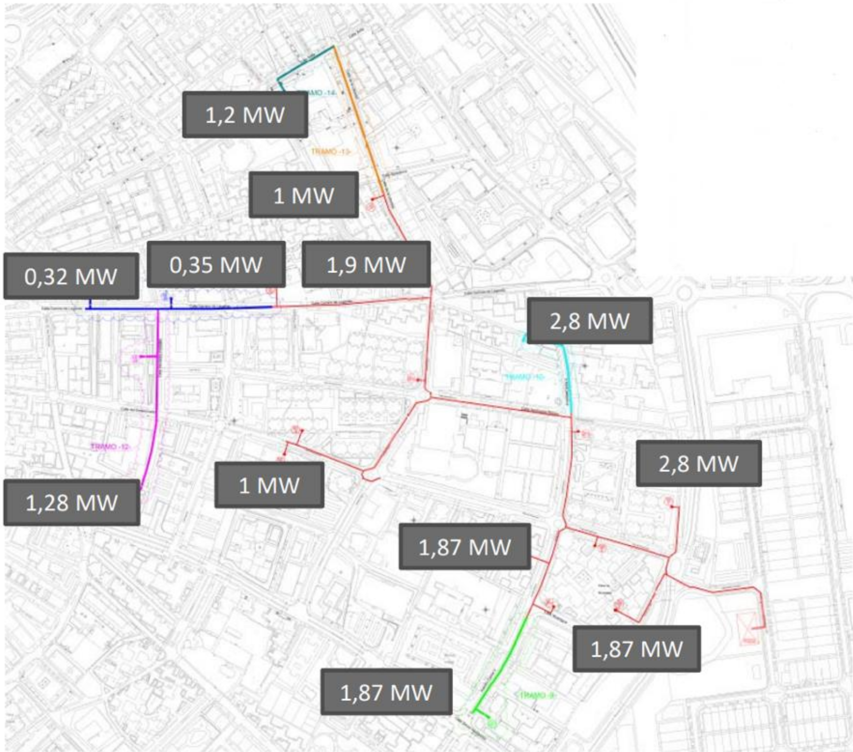

Figure 12. Map of Móstoles District Heating network and the capacity of the 12 substations. The red line is the main transmission line from the biomass central plant, on the west side, located in an industrial complex (Veolia, 2019)

Approximately 2 500 dwellings in community buildings (i.e. apartments) are served by the network. The plan is to extend the network in future to supply 7 000 customers (Veolia, 2016).

Planning took four years in total. The district heating company was lacking engineering expertise so they involved an industrial engineering partner from the beginning. The project needed to receive support at municipal level to obtain permits and establish the location of the heat plant. There were no obstacles related to the municipal approval procedure (even though the city did not have much experience in dealing with DH-related requests). The project started with a main heat source in a centralised location and expands the network from there (organic growth). The power plant can be built any time because it is at a central location that does not cause disruption for the citizens.

At a commercial level, it was key to disseminate the concept and advantages of the heating plant (compared to heating with fossil fuels) among potential customers, and to establish grid partners before starting construction (Veolia, 2016).

During planning, Móstoles District Heating had to search for funding for the project. This was difficult. At the time no subsidies were available and no bank loan was possible. The commissioning of the heat network had an investment of EUR 7 million associated with it, which included the construction of the biomass plant and the network itself, consisting of four kilometres of pipelines and 13 exchange substations, one for each community of neighbours connected to the network. The second phase had an investment of EUR 12 million associated with it and was financed by the SCEEF Fund and managed by SUMA Capital and Veolia (Euroheat, 2019d).

Starting by involving large customers was a strategy used during planning. The DH company focused on contracting community buildings using community boilers. These were mostly built before 1985. Targeting small consumers (individual heated buildings) was not on the agenda.

According to the DH company it is of crucial importance to teach the local stakeholders about green policy in order to get support for the project and convince them to participate. During planning there were several public consultations and client meetings organised with potential customers (community buildings) about how to change to a more sustainable way of heating. More specifically to teach about green policy, the need to switch to another fuel without CO_2 emissions, about biomass and sustainability, and price of heat generated by burning biomass (compared to gas it is 10-15% cheaper according to the DH company). There was some resistance from potential customers regarding the use of biomass, but in the informative meetings it was explained how the central plant works and how the pollution is reduced through filtering systems, which answered the doubts.

The DH company communicated about the plans and construction work of the network via their newsletter. Construction work only happened during summer months (in which heat demand is minimal) to minimise disruption of normal city life.

It is a “green” project. The biomass source is harvested from local forests. In Spain a lot of forest fires are caused by dead wood in the forest, which accumulates when there is a lack of forest maintenance. This wood can be used as a DH source and at the same time prevent (or reduce the risk of) forest fires. The understanding is that the vast majority of biomass came from the nearby forests and that it primarily is residual biomass, which would otherwise not be usable for other purposes. It is an abundant and secure source that is considered environmental friendly. Consideration of how sustainable biomass will be defined in future was not discussed during the interview. In this case, using wood chips also provides a way to increase local employment in forestry, which is an important benefit for the people.

There was no co-ordination or alignment with maintenance works (water, electricity, gas). This was not possible at the time, but would be recommended for future projects.

The municipality takes care of urban spatial planning. For the project there was not much collaboration with the municipality. No one in the municipality was basically involved in the district heating part of the development. The approval was more from a spatial planning perspective. The fact that the municipal representative was not familiar with district heating was hence not considered as an issue. A Mayor agreement was signed and licenses to construct and dig were needed from the municipality. Aside from that there was communication with the municipality in order to look for ways to minimise disruption of normal city life during construction.

For the network there is a fixed tariff that comprises about 10-20% of total costs a customer has to pay annually. The rest of the annual charge is based on heat usage. There is no initial connection fee.

4.7.4 Identified success factors

Extracted best practices for the case based on the interviews are summarised below. Practices in **bold** were emphasised by the interviewees during the interviews and can therefore be regarded as being most important for this particular case. Practices in ***bold Italic*** are recommendations for best practices that can be considered as possible improvement or attention points for future projects.

Planning – Business case and costs

- **Start with large potential customers (e.g. community buildings or apartments), talk to them beforehand.**
- Start with a main heat source in a centralised location and expand the network from there (organic growth).

Planning – Social acceptance

- **Organise meetings with clients / engage with stakeholders**
- **Important to inform people about green policy. Clear communication about biomass sustainability and price was key. Send out newsletters to inform people.**
- Co-ordinate with municipality to arrange options to minimise disruption of city life during construction.

Planning – Other strategic items

- Focus on locally available renewable or waste energy sources (these have to be secure, environmental friendly). In this case, using wood chips provides a way to increase local employment in forestry. Utilising locally harvested wood is a way to reduce risk of forest fires in the area.
- If lacking expertise, involve a partner with the expertise from the beginning

Construction – Business case and costs

- Construction co-ordination meetings

Construction – Social acceptance

- **Only build during summer months**

- ***If possible align construction with modernisation of other underground infrastructure by other utilities***

4.8 Olsztyn

The case of Poland gives an example of an existing DH system shifting away from coal to alternative, less polluting, heat sources such as a waste-to-energy plant and a biomass plant. This case is not about extension of the DH system, but rather about optimising the use of heat of current consumers.

4.8.1 Historical and current background

As Poland has a relatively cold climate, a large share (66%) of the total energy consumption in buildings is used for space heating (Heat Roadmap Europe, 2017). Poland has a past marked by the Soviet Union, which developed DH as the main heating system in the countries under its rule. That explains why DH plays a dominant role in the heating sector in Poland. There are more than 300 DH networks in the country (IEA, 2016). In 2017, DH networks supplied 42% of the total heat demand in Poland, which makes it the second largest producer of district heat delivery in the EU (Euroheat, 2021e). Around 75% of heat for DH is produced from burning coal in 2018 (Energy Post EU, 2020). Such heat production is associated with high carbon emissions and local air pollution, including dust and toxic oxides of nitrogen and sulphur (Energy Post EU, 2020). Other heat sources that are used in DH are renewable energy (biomass), incineration, and gas. Incineration has a small share in total heat generation, but it is expected to increase in the future (IEA, 2016).

The first DH systems in Poland were constructed in the 19th century. They were coal fired, located in Warsaw and used to both produce heat and electricity. In the 20th century, old coal-fired DH systems got modernised due to slow degradation. The last 20 years, Polish DH systems have seen significant improvements of heat generation, by achieving higher efficiency, and lowering heat losses during transmission and distribution (Wojdyga and Chorzelski, 2017).

Despite Poland's modernisation efforts for DH systems, it still relies mainly on coal. EU regulations on CO_2 emissions force Poland to strongly reduce its emissions. Therefore, the shift to a renewable heating system is of key importance (IEA, 2021). Candidate heat sources to replace coal are incineration, industrial waste heat, biomass and gas. A concern however is that if the transition goes too quickly it could have a major impact on national heat prices.

4.8.2 Regulatory framework

The main authority in the heating sector is the Energy Regulatory Office (ERO), whose main responsibilities are granting licenses for the generation and distribution of heat, and regulating heat tariffs (IEA, 2021). The ERO plays in important role in the determination of tariffs. They publish the benchmark and also the national average tariffs.

The ERO approves DH tariffs set by heating companies when all the costs needed to supply this heat are justified. Tariffs must be set in accordance with the principles laid out in the Energy Law (established in 1997), which allows for a reasonable return of capital for the companies while protecting the customers against unjustified price levels (IEA, 2016). In such a regulated market, the incentive to produce heat in a more cost-efficient manner is relatively low. Therefore, the Polish government plans to create an incentive for lower prices. These plans are stated in the Energy Policy for Poland (EPP) 2030 (Ministry of Energy Poland, 2020a). This policy aims to move Poland from a highly regulated system to a more deregulated market system, where different suppliers compete on price. Municipalities are required to develop plans to lower the costs of the DH systems (Ministry of Energy Poland, 2020a). The EPP also stimulates CHP and waste heat from industry. Besides this, the EPP sets targets for the energy mix, such as a minimum share of cogeneration, renewable and nuclear energy (Ministry of Energy Poland, 2020a).

There is an obligation In Poland for consumers to connect to DH. In areas where there are technical conditions to supply heat from an energy efficient heating system, customers should use DH first, unless they use a greener solution (Ministry of Energy Poland, 2020b). To increase the use of DH in Poland, the plan is to extend the current obligation to all centralised district heating systems for all buildings (Ministry of Energy Poland, 2020b).

There is a tax relief measure for heat modernisation projects (ongoing, period 2018-2030). This includes heat pumps, solar heat connections, insulation measures, and also a connection to a heating network. The measure allows expenses for the project to be deducted from the income of taxpayers. The measure applies only to existing buildings (Odyssee-Mure, 2021).

There is also a heat modernisation fund (ongoing measure until 2027), for investors in modern heat projects, including local district heating networks. The scheme is available to all investors, such as owners or administrators of buildings, local heat sources and local heat distribution networks. Supported projects include end-use improvements in residential and tertiary buildings, reduction of energy losses in heat distribution networks and the substitution of conventional energy sources by renewable energy. Under the heat modernisation programme investors receive a premium of 20% of the loan used for implementing an eligible project upon completion of the project (Odyssee-Mure, 2021).

In Poland, municipalities have the obligation to develop a local plan for the supply of heat, electricity and gaseous fuels, just as in many other countries. The city is obliged to ensure that inhabitants receive the heat they need. There is a document of the heat security. According to the Law in Poland, every municipality must monitor projects with respect to energy delivery such as heat, but also water. The municipality is the owner and has the local responsibility to monitor the project and develop it further.

4.8.3 Case study / interview

Olsztyn is located in the northeast of Poland and has a population of around 170 000 people. The existing DH network is currently being modernised by the addition of more sustainable heat sources. The network, 176 km long, has a heat capacity of 250 MW, and supplies heat to 60% of all residential buildings and public buildings in the city (ERBD, 2015). The DH infrastructure in Olsztyn was commissioned by MPEC, a heat supplier that is owned by the municipality. MPEC operates and controls the DH infrastructure. The case involved modernising the existing coal-fired DH system. An incinerator supplying heat in Olsztyn is currently being built through a public-private partnership between MPEC and a private partner (European Commission, 2021). The private partner will build and operate the incineration plant for the period of 25 years.

In 2011, a private company (Michelin tyre factory) owning a factory-related CHP plant in the city and contractually obliged to supply the heat to the city network, decided to terminate the contract with MPEC for heat supply. This created a deficit in heat generation capacity in the DH system and therefore new capacity needed to be added. That same year, MPEC, the municipality and an external expert started the planning stage to add a new heat source to the network. The main idea behind the project was to diversify the fuel mix and shift away from coal (the share of coal was almost 99%). When thinking of the alternative heat resources that could be used two things were important: 1) environmental friendliness, and 2) local availability and security. Olsztyn is surrounded by woodlands, which means there is a large potential for biomass. The aim was to reduce 50% of the coal use and eventually combine biomass, waste and gas. Those three together will then account for approximately 60% of heat generation. The heating company is now in the middle of the project, which runs until 2023. The role of the municipality is to monitor the progress. There are no real issues with respect to the construction process. The biomass plant construction process had some months of delay, but currently the source is in full operation. The construction of the incineration plant is going according to schedule.

At the planning stage of the DH system, many different positive and negative scenarios were developed by the municipality, to analyse positive and negative trends that have affect the business case. This was done to get a recognition of the legal, environmental and overall aspects to consider. This approach also caused the planning stage to take longer. Because the future is uncertain and it is a long-term project it is important is to stay flexible for these changes. It is however difficult to predict them. Also, reacting to changes is difficult, especially after things have already been decided. For example in the urban planning phase, it was the case that biomass and waste are not covered by the European Emissions Trading Scheme (EU-ETS). But it may be covered by the EU-ETS in future, which changes perceptions and the business model.

The heating company is obliged by the law to receive an environmental permit. Part of this process is to carry out a series of public consultations and to continue the dialogue as the project develops. In 2015, there was citizen engagement initiated by the City Council. MPEC organised an information campaign related to the main ideas of the incineration and the biomass plant. It involved making the public aware of the advantages and disadvantages of the new installation, and how MPEC plans to deal with the disadvantages. After MPEC received their permission, they also continued this dialogue with the general public. In the planning phase, there was a group that opposed the plans for the incineration plant. The dialogue helped to reassure them. It did not really slow the process down in the end. At the moment there is no opposition to the construction work anymore.

MPEC commissioned the construction of the plant to a private partner –Dobra Energia dla Olsztyna (DEDO) under a public-private partnership contract (European Commission, 2021). The construction did not cause disruption to city life because the plant is on the outskirts of the city. MPEC also co-operated with other construction projects in the same area to reduce the impact on the city. In 2021, the plant's construction was roughly halfway complete. MPEC prepared the DH concept (design) and supervised everything from the start. But the detailed design and construction was done by the private partner. For MPEC this was the right decision because it meant they gained a lot of experience at the urban planning phase.

The project received subsidy from the EU (executed through the national environmental programme) for the construction of the incinerator and the biomass boiler. Very specific terms had to be met to apply for the EU funds however. MPEC needed to make the project perfectly suited to the conditions set out by the funding programme. A downside of this it that it does not allow for flexibility of the applications. For instance the requirements set out that it not only had to be a renewable source, but also set out the specific type of biomass, the permitted environmental effect, the efficiency, and the capacity range.

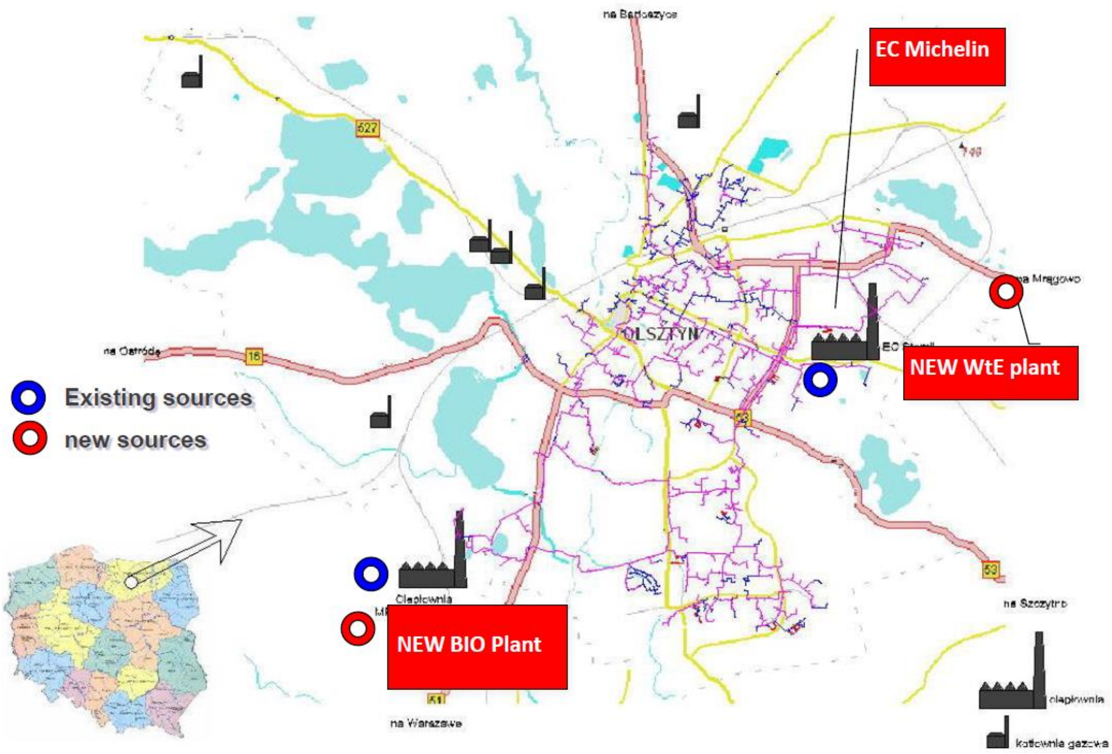

Figure 13. Locations of the new heating plant and the DH system in Olsztyn (the site of the new WtE plant is on the outskirts of the city) (MPEC Olsztyn, 2021)

Figure 14. Impression of the waste-to-energy district heating plant (Link: http://ec.olsztyn.pl/plebiscyt)

The new steps foreseen related to incineration in the context of the entire system are not really expansion but more conversion. MPEC does not expect a large increase in the number of consumers in the coming years. But the goal is not expansion but rather optimising the use of heat of current consumers.

The general heat capacity is 250 MW. After the incorporation of new heat sources, it will be about 260 MW. So a small expansion in capacity will take place, but the goal is to gradually replace coal with RES. There will be new consumers in the future but this will not entail a growth of demand as the company has been observing a trend of decreasing heat demand per consumer. The capacity of the system does not have to change; better insulation in existing buildings can be balanced out by connecting new consumers. If heat demand decreases, there is an opportunity to further reduce the remaining coal in the fuel mix.

MPEC calculates the tariffs, taking into account all the costs and returns. However, every tariff has to be approved by the national regulatory office, which examines in detail whether the calculation follows the regulations set out by the law. The price of heat itself is the same for all consumers, while the transmission fees depend on the model of connection to the network (for example whether the substation belongs to MPEC or the consumer). A recommendation to minimise the impact of construction of new plants is to avoid the busiest city locations. When it comes to existing network construction works within the city, the way to reduce impacts is to combine the activities with other works in the city, like modernisation of other underground networks by other companies in the same location. MPEC also tries to use trenchless construction methods whenever it is possible for underground works.

In order to lower the costs the municipality tries to adhere to BAT. Thorough research on available construction methods enables the choice of solutions that are innovative, but also guarantees the required level of security.

4.8.4 Identified success factors

Planning – Business case and costs

- **Create multiple scenarios – positive and negative – on how the project might develop.** In the planning phase it is important to have a recognition of the general trends that exist that affect the project: legal, environmental and overall aspects to consider (e.g. biomass is not now covered by the EU-ETS, but this might change in future).

Planning - Governance

- Have a long-term strategy to connect heating systems.

Planning - Social acceptance

- **Series of public consultations and to continue the dialogue as the project develops (after environmental permission is received).**
- Set up an information campaign for customers to minimise doubt for new heat sources.

Planning - Regulation, policy and subsidy

- **Attain financing from the EU for the heat sources (e.g. in this case biomass boiler and the incinerator).**

Planning – Other strategic items

- **Focus on locally available renewable or waste heat energy sources (these have to be secure, environmental friendly). Have a view of the resources locally (e.g. conduct a potential analysis for renewables and waste-to-energy).**
- **Become more flexible (future proof) in heat supply by diversifying the heat sources and fuels**

Construction – Business case and costs

- **Prepare the DH network conceptual design and supervise everything from the start. Let a subcontractor company do the detailed design and construction.**

- Adhere to BAT. Thorough research on available construction methods and always try to choose the solutions that are innovative, but also guarantee the required level of security.

Construction – Social acceptance

- **Build heat source outside the city centre.**
- ***Combine the activities with other works, like modernisation of other underground networks by other companies in the same location***.
- ***Use trenchless construction methods for underground works whenever possible.***

5 Best practices in district heating – in-depth understanding of success factors

In the previous chapter, eight cases and their best practices were presented. In this chapter a cross-case analysis is performed on the best practices of the cases.

First, the best practices are presented in a categorised overview. On the basis of this overview the analysis is performed and the general best practices are presented.

5.1 Categorised overview of best practices

Table 6 and Table 7 show an overview of the best practices for the urban planning and construction phases. Table 6 is split over two pages. For each case and category the best practices are given. Sometimes, a case has mentioned several best practices for a category and sometimes it has mentioned none. The cases are:

- Storvorde, Aalborg, Denmark;
- Antwerp, Belgium;
- Salaspils, Latvia;
- Drechtsteden, Netherlands;
- Milan, Italy;
- Bruchsal, Germany;
- Olsztyn, Poland;
- Mostoles, Madrid, Spain.

The categories are:

- Business case and costs;
- Governance;
- Social acceptance;
- Regulation, policy and subsidy;
- Other strategic items.

Best practices in **bold** were emphasised by the interviewees during the interviews and can therefore be regarded as being most important for a particular case. Best practices in ***bold italics*** are recommendations for best practices that can be considered as possible improvement or attention points for future projects.

Table 6. Overview of the best practices for the urban planning phase by case and category. Continued on the next page.

Case	Business case and costs	Governance	Social acceptance	Regulation, policy and subsidy	Other strategic items
Storvorde, Aalborg, Denmark	- Organic growth of the network.	- Have a certain scale of organisation.	**- Involve customers as early as possible.** - Take away the investment barriers for customers, e.g. by leasing the heat delivery set.	- Keep regulation and tariffs simple and understandable. **- Have a smooth process for approvals from the municipality.**	**- Transparent and open process.** **- Have a pre-dialogue of the project between the municipality and the company.**
Antwerp, Belgium	- Build with overcapacity. - Have customers with a large demand. - Work together with other utilities. - Adjust the planning of DH to that of other utilities. - Take time to make clear agreements.			- Policy should have a guiding role.	**- When you lack expertise, collaborate with partners who do have this expertise.**
Salaspils, Latvia	**- Take your time to make a proper integrated system design** **- Plan for a well-structured system** - Use thermal energy storage.		- Inform local people on energy issues. - Perform public assessments and involve citizens.	**- Use EU support funds (such as EU cohesion fund) to finance projects in relatively low-income countries** - Use tariff regulation to provide stable tariffs to customers	**- Learn about technology from others.** **- Become more flexible (future proof) in heat supply by diversifying the heat sources and fuels** - Focus on locally available renewable energy sources. **- Use a detailed procurement procedure with performance criteria** **- Involve only highly experienced contractors and installers** **- If lacking expertise, involve a partner with the expertise from the beginning**
Drechtsteden, Netherlands	- Start with large buildings. **- Visualise the business case from the start.** **- Have a clear risk and responsibility package from the beginning.** **- Phased roll-out.** **- Create a concrete deadline.**	- Define a 30-year ambition with all stakeholders, and then work on a 5-year plan.	**- Communication prior, during and after project execution with local stakeholders.** **- Work with all stakeholders to make buildings ready for DH.**		- A transparent process and joint commitment of the stakeholders involved. - Take your time for the planning phase. - Create understanding and trust.

Milan, Italy	**- Phased roll-out of the network** **- Dialogues between the municipality and DH company about the network routing.** - Use a decision support tool to optimise the business case and decision making. - ***Keep track of heat losses for business case.***		**- Organise meetings and engage with stakeholders** - ***Support from political level would be helpful to improve the image of DH.***	- ***Regulation, policy (and subsidies) should all be guiding DH development.*** ***- Keep the municipal approval process as simple as possible*** ***- Utilise the potential of waste-to-energy, biomass and solar thermal for DH with subsidies.*** ***- National and local government need to refine their national heat strategy***	- If lacking expertise, involve a partner with the expertise from the beginning. - Focus on locally available renewable or waste energy sources.
Bruchsal, Germany	- Focus on locally available renewable energy sources. - Use hot water storage. - Start planning with large consumers. - Create an overview of the heat demand in an area in the beginning. - If the situations asks for it, break up a tender in multiple smaller parts. - Over-dimension the pipes. - Work together with other projects.	- Long-term strategy to add heating systems and connect with existing systems. - Have an overview of public buildings with a large energy demand.	- Plan the pipe routing through green areas to reduce the impact on city life. - Offer an all-in price to customers to take away the investment barrier. - Involve the local population during the planning phase.	- Political (and social) climate is relevant. - A government can add conditions to subsidies to steer on what they find important.	- Have clear goals and targets from the beginning of the project. - Take your time for the planning phase. - If you lack expertise include a company with this expertise from the beginning.
Olsztyn, Poland	**- Create multiple scenarios on how the project might develop.**	- Have a long-term strategy to connect heating systems	**- Have a series of public consultations and continue the dialogue as the project develops** - Set up an information campaign for customers **-Build heat source outside the city centre**	**- Financing from the EU for the heat sources**	**- Focus on locally available renewable or waste energy sources.** **- Become more flexible (future proof) in heat supply by diversifying the heat sources and fuels**
Móstoles, Madrid, Spain	- **Start with large potential customers.** - Start with a main heat source in a centralised location and expand the network from there.		- **Organise meetings with clients and engage with stakeholders.** **- Inform people about green policy.** - Co-ordinate with municipality to arrange options to minimise disruption of city life during construction.		- Focus on locally available renewable or waste energy sources. - If lacking expertise, involve a partner with the expertise from the beginning.

Table 7. Overview of the best practices for the construction phase for the cases and categories.

Case	Business case and costs	Social acceptance	Other strategic items
Storvorde, Aalborg, Denmark	- Use the best pipe technology available. - Lower the temperature to increase efficiency. - Install smart meters to monitor the temperatures	- Co-ordinate with utilities to cause less disruption - Only do construction outside the winter period	
Antwerp, Belgium	- Work together with other utilities ***- Have an appropriate balance between testing and risks***		
Salaspils, Latvia	- **Weekly construction co-ordination meetings** - **Performance tests heat sources** - **Involve a wide range of professionals** **- Choose a quality supervision company**		
Drechtsteden, Netherlands	- Structural agreements e.g. polluted soil. - Appoint someone for all matters regarding "below the ground". **- Be prepared for hiccups.** **- Make and keep deadlines.** **- Do not aim at the optimal, but the possible solution.**		- Co-ordination meetings. - Create a document for the entire process. - Make an overlap between planning phase and the planning of construction. - Create trust among all involved.
Milan, Italy	**- Construction co-ordination meetings.** - Be prepared for hiccups. - ***Use best pipe technology.***	- **Plan all the construction works and co-ordinate with the police on how to disrupt traffic** - Execute project in phases to minimise disruption to normal city life	- Make an overlap between planning phase and construction
Bruchsal, Germany	- Use proven systems to minimise the risks of the project. - Solve problems as much as possible before you start construction.		- Create bonds with partners for future projects.
Olsztyn, Poland	**- Prepare the DH network conceptual design and supervise everything from the start. Let a subcontractor company do the detailed design and construction.** - Adhere to BAT.	- ***Combine the activities with other utility works*** ***- Use methods that avoid actual digging whenever possible***	
Móstoles, Madrid, Spain	- Construction co-ordination meetings.	**- Only build during summer months** - ***If possible align construction with modernisation of other underground infrastructure***	

5.2 Cross-case analysis

The general best practices for district heating planning and construction are presented in this section. First, the best practices for the urban planning phase will be given, followed by the best practices for the construction phase.

5.2.1 Urban planning phase

In this section we present the general best practices for the urban planning phase. Table 8 shows an overview of the general best practices. These general best practices are based on the best practices from Table 6. For each category it has been determined which best practices have been mentioned most often and are seen as most important. In the following paragraphs the general best practices will be explained further for each category.

Table 8. Overview of the general best practices for the urban planning phase.

Category	General best practices	Context
Business case and costs	Start planning with large consumers.	This can make the business case and it allows for organic growth: first establish a network with large consumers and then expand to the smaller consumers. Furthermore, the entry level (percentage of consumers who have been contracted before construction starts) can be lower.
	Focus on locally available renewable energy sources or waste energy sources.	Necessary for the heat transition. It was mentioned several times that there is still a lot of untapped heat potential. It will make a DH network more futureproof. Each location and project is different, so the solutions will be different everywhere. Look at what is available locally.
	Work together with other utilities.	This was mentioned several times and it mainly reduces cost. Different perspectives: in some cases only when it occurs, in other cases this collaboration with other utilities dictates the planning of DH. As a side note, cases are known in which this collaboration has actually delayed the construction of DH and increased the cost, so one has to be sure that the planning aligns.
	Have a clear risk and responsibility package from the beginning.	Important to do this during the planning phase, to avoid trouble during the construction phase and to help in settling disputes.
	Visualise the business case from the start, including what a change in conditions will do.	Changes are bound to happen, is the business case still positive if these changes occur? What can be done to counter these changes?
Governance	Have a long-term heat strategy.	Do not only focus on one project, but have a longer horizon, e.g. for organic growth of a DH network.
	Have an overview of public buildings with a large energy demand.	This can give indications on what are good places to start a DH network. Can also be extended to include private buildings or business parks. Furthermore, these buildings can be seen as long-term consumers.
Social acceptance	Communication prior, during and after project execution with local stakeholders.	Ensure people are updated on the process, educate them (on sustainability and DH) and make them enthusiastic for DH.
	Involve the local population during the planning phase.	This goes one step further than informing people. Also listen to their concerns and take these into account.
	Remove the investment barriers for customers, e.g. by leasing the heat delivery set.	High entry-cost, e.g. connection cost, will prevent uptake and hence influence both the business case and a city's sustainability agenda.
Regulation, policy and subsidy	Have a smooth process for approvals from the municipality.	In some cases we saw that communication between operators and municipalities was arduous, mainly because there were several departments within the municipality which had to be contacted. A smooth process will reduce time and costs.
	Policy should have a guiding role.	Both on a national and local level. Both can give subsidies and support to make DH possible and have influence on it, e.g. renewable heat sources and communication with the people. Regulation can also help, e.g. new buildings cannot be

		heated by gas. Local governments should have a long term heat plan which can include DH. A positive climate for DH will also help with social acceptance.
	Use EU support funds to finance projects in relatively low income countries.	Low-income countries benefit from subsidies from EU-funds.
Other strategic items	When you lack knowledge or experience, collaborate with (international) partners who do have this knowledge and experience.	There are different levels of expertise between countries, municipalities and projects. Be sure to involve others when lacking expertise. Important to do this from the beginning of the project. Focus also on acquiring knowledge during the project.
	Take your time for the planning phase.	Most cases mentioned that if the planning phase is executed correctly, then the construction phase is "easy". And if hiccups occurred during the construction phase, then usually the solution was to spend more time during the planning phase.
	A transparent process and joint commitment of the stakeholders involved.	It is important to have a transparent process. This will ensure acceptance of the project. The stakeholders should agree on the plan.

5.2.1.1 Business case and costs

Start planning with large consumers. This general best practice was recognised by most cases. Other best practices which complement this general best practice are to have an organic growth of the district heating network and to build with an overcapacity to make the network futureproof for expansion and connection to other heating systems. The business case is positively influenced by starting with large consumers. In the Bruchsal case we saw that the business case was already positive for the two public schools. Adding consumers with smaller demand had a positive effect on the business case, but it was not necessary essential. In the Aalborg case we saw that they split an area into multiple parts. By starting with the parts with the large apartment buildings, it was easier to expand to the other parts in the area. In this way there is an organic growth of the district heating network. To build with overcapacity is an investment for a long-term heat system, as the costs are higher for the current project, but will be lower for future projects when the district heating system is expanded or connected to other systems. To avoid the risk of too little demand, district heating companies usually have an entry level. This is a percentage of clients that has to be contracted before construction will start. By starting with large consumers, it becomes easier to reach the entry level and construction can start sooner.

Focus on locally available renewable energy sources or waste energy sources. To move towards more sustainable ways of heating in the built environment it is important to invest in heating options that are available, have security of supply and cause less emissions. A regional potential assessment helps to identify these heat sources. Utilising relatively nearby resources can contribute to reduced heat production costs, and therefore be beneficial for the business case. In Latvia, it turned out that there was sufficient potential for solar thermal to make an interesting business case. In Móstoles, biomass (woodchips) could be harvested at relatively low cost while at the same time stimulating local forestry. Some cases such as Italy and Poland also show that using CHP plants running on municipal waste can be an interesting option to quickly reduce emissions.

Work together with other utilities. When working with other utilities, such as sewage, electrical or pavement the costs can be distributed over the different projects, such that the costs per project are lower. Some cases, such as Bruchsal, Germany, were planning district heating and coincidentally were able to work together with other utilities. In the case of Bruchsal, Germany they worked together with the refurbishing of the pavement. This did have an effect on the routing that was chosen. In Antwerp we saw that the planning of district heating was tuned to the planning of other excavation activities. In the business park the sewage system had to be renewed. This was seen as the perfect time to start working on a district heating network. Other reasons for working together with other utilities will be seen in the social acceptance category. However, it is not always possible to work together with other utilities, or do it in a cost-effective way. If the planning of the two construction works do not fit together it can actually increase costs instead of decreasing them.

Have a clear risk and responsibility package from the beginning. Have clear agreements on risks and responsibilities from the beginning of the urban planning phase. There will be hiccups during the construction phase and clear agreements made during the planning phase can avoid disagreements and problems during the construction phase.

Visualise the business case from the start, including what a change in conditions will do. A business-as-usual business case should be created first. For this one should create an overview of the heat demand in an area in the beginning to determine whether district heating can be an economic solution. Check whether you have a positive business case from the beginning. As there are uncertainties during the planning phase, one should also take into account how a change in conditions affects the business case, e.g. construction takes longer than expected, or the heat demand is lower than expected. Doing this creates insights into the worst-case business case and the potential of the business case. One can use a decision support tool to optimise the business case and decision making.

5.2.1.2 Governance

Have a long-term heat strategy. Municipalities (and operators) should define a long-term heat strategy. In Bruchsal this long-term heat strategy focused on adding new heat systems and connecting these to existing heat systems. In Drechtsteden, they advised the creation of a 30-year ambition with all stakeholders and then to work on a 5-year plan. The 30-year ambition is the dot on the horizon and this can be translated to concrete actions and plans in the present.

Have an overview of public buildings with a large energy demand. This general best practice relates to the general best practice of starting planning with large consumers from the Business case and costs category. In Bruchsal they started planning with a public school that had to renew its heating system. During the planning phase they found out that another public school had to update its heating system as well in two years. By creating a project based around these two public schools, a district heating network was able to be set up. They want to do such projects in a more systematic manner. To do this, they suggest the creation of an overview of public buildings with high energy demand. This overview could also include when a building has to renew its heating system. This overview can be the start of project ideas. This general best practice can be extended to all buildings with high energy demand, e.g. business parks.

5.2.1.3 Social acceptance

Communication prior, during and after project execution with local stakeholders. Communicate clearly with local stakeholders, including the general public. This should be done prior to the project (informing about what will happen), during the project (informing about the process of the project) and after project execution (to update on the project). This involves informing and educating the local population on energy issues to create enthusiasm for district heating and the project.

Involve the local population during the urban planning phase. This general best practice relates to the previous best practice, but requires a more active role from the local population. Instead of only informing the local population, they can also be actively involved. This can create more support for the project from the local population. This involvement can be done through workshops. It does not mean that the population will decide which grid design has to be used, but they can influence this decision. It requires an open mind-set from the municipality and operator.

Take away the investment barriers for customers, e.g. by leasing the heat delivery set. It can be a big investment for people to connect to a district heating network. The investment barrier can be taken away or lowered by leasing the heat delivery set. Instead of a single investment, consumers pay a monthly fee. This has been introduced in Aalborg and Bruchsal. In the Netherlands this is already a standard practice.

5.2.1.4 Regulation, policy and subsidy

It is difficult to determine general best practices for this category, as each case comes from a different country, which has a different context of regulation, policy and subsidy. The general best practices mentioned below were mentioned by several cases. They do not prescribe which regulation is best for district heating.

Have a smooth process for approvals from the municipality. Municipalities have a special role in the planning of district heating, as they have to approve and supply permits. The size of the role differs between countries. In Denmark a socio-economic analysis has to be performed; this is regulated. These analyses are made by operators and municipalities have to check them. It is important to have a smooth process as this can save time and ensure a clear and smooth planning phase. An example is to have one contact point between the operator and municipality, such that clear agreements can be made. If there are multiple contact points, then agreements can be in conflict with each other. It can also help to have a dialogue at the beginning of the project. This was called a pre-dialogue by one of the interviewees. Such a pre-dialogue aligns the ideas of the projects of the operator and municipality and can smoothen the process.

Policy should have a guiding role. Local and national policies play a role to encourage district heating. This can also be regulated, e.g. by not allowing new buildings to be heated by gas. This makes district heating an interesting option. A government can also add conditions to subsidies to steer on what they find important, e.g. include local population or have low CO_2 emissions. In the Milan case they mentioned that there is a large untapped potential for waste-to-energy, biomass, and solar thermal for district heating and it could grow much more if a subsidy was provided by the government. In the governance category a general best practice was to have a long-term heat strategy. This is also a general best practice for national and local governments. They should also get support, from the (local) population, for these strategies. The national government will play a larger role with the prohibitions, while the local governments focus on long-term heat strategy. Both governments play a role with subsidies.

Use EU support funds to finance projects in relatively low-income countries. In the Olsztyn and Salaspils cases, EU funding played an important role and made the projects possible. Low-income countries benefit from subsidies from EU funds.

5.2.1.5 Other strategic items

When you lack knowledge or experience, collaborate with (international) partners who do have this knowledge and experience. The level of expertise differs between countries, municipalities and projects. For many people involved in projects, it is a new subject and they lack expertise. If this is the case, then it is important to involve and collaborate with partners who have this expertise. In several cases this was only done during the planning phase when it became clear that expertise was missing. It is a general best practice to involve partners with expertise from the beginning of the planning phase. While doing this, one should acquire knowledge and expertise, which will make future projects easier.

Take your time for the urban planning phase. In many cases the planning phase took a long time. However, this was seen as something positive. It is important to take your time for the planning phase as the different ideas of the projects from the different stakeholders have to converge and most problems should be solved during the planning phase and before the construction phase.

A transparent process and joint commitment of the stakeholders involved. During this phase understanding and trust should be created between all stakeholders involved. For this, clear communication is necessary. In the Aalborg case they found it useful to have a pre-dialogue between the operator and the municipality. As a result, everyone has the same knowledge of the project and the interests are aligned. Such a pre-dialogue can also be held with other stakeholders.

5.2.2 Construction phase

In this section we present the general best practices for the construction phase. Table 9 shows an overview of the general best practices. These general best practices are based on the best practices from Table 7. For the categories Business case and costs, Social acceptance, and Other strategic items it has been determined which best practices have been mentioned most often and are seen as most important. No general best practices were identified for the categories Governance and Regulation, policy and subsidy. In the following paragraphs the general best practices will be explained further for each category.

Table 9. Overview of the general best practices for the construction phase.

Category	General best practices	Context
Business case and costs	Adhere to the BAT.	What is the BAT might differ between projects. It is a balance between investment costs, operational costs and other relevant criteria such as sustainability. Investigate your options and choose the one which is best according to your criteria. It is good to share knowledge and have clear EU standards. Note that BAT is not necessarily the most advanced, e.g. extreme low temperature, but can also be best available well tested and documented technology. It can also depend on the experience of the ones involved in the project.
	Work together with other utilities.	Similar to the general best practice in the planning phase. It can reduce costs.
	Lower the supply temperature to increase efficiency.	Still high temperature grids are being built, while low temperature (LT) grids have a much higher efficiency. Also LT

		grids are able to use more sources, such as the waste heat of nearby buildings. This will also make the grid futureproof.
	Be prepared for hiccups.	Connects to the clear responsibility package as mentioned in the planning phase. Being prepared for hiccups will decrease the delay and costs. Important to learn from others and previous projects on what are typical hiccups.
Social acceptance	Only do construction outside the winter period.	Depends on the location, in a cold climate this can be an important general best practice, while in a warmer climate it is not as important.
	Co-ordinate with utilities to cause less disruption.	Working together with utilities does not only reduce the costs of the project, but also limits the disruption caused by construction. As such, it can improve the social acceptance of DH, e.g. by avoiding traffic disturbance.
	Execute project in phases to minimise disruption to normal city life.	Depends on the location, in a busy city centre it is important, in a small town it is not as important.
Other strategic items	Have regular co-ordination meetings.	This was especially mentioned by cases in which this was not done. Then the overview of the project can be lost quickly.
	Put more time in the project to create bonds with partners for future projects.	This general best practice is especially important for parties that are new to DH. Invest time in the first projects, such that future projects will go smoother.

5.2.2.1 Business case and costs

Adhere to the BAT. What is BAT might differ between projects. In the Aalborg case they mentioned that they use the best pipe technology available, with high insulation values. It is a balance between higher investment costs, lower operational costs and other relevant criteria such as sustainability. One choice might be cheaper during construction, but more expensive overall. Investigate your options and choose the one that is best according to your criteria. It is good to share knowledge and have clear EU standards. Note that the BAT is not necessarily the most advanced, e.g. extreme low temperature, but can also be the best available well tested and documented technology. It can also depend on the experience of the ones involved in the project.

Work together with other utilities. By working together, the costs of construction can be lowered. This general best practice was also mentioned for the urban planning phase. Again, one has to be careful that the planning of the projects can be aligned. Otherwise, this can actually raise costs instead of decreasing them.

Lower the temperature to increase efficiency. A lower temperature results in a more efficient district heating network, as the heat losses are lower. For new district heating networks this can be accomplished during the urban planning phase when designing the network. This has an effect on the design of the network and on the choice of heat sources. In the Aalborg case they also work on lowering the temperature for their existing district heating network.

Be prepared for hiccups. During the construction phase hiccups will almost surely occur. It is important to be prepared for these hiccups. This also relates to the general best practice in the urban planning phase to create a clear risk and responsibility package. This package can help during these hiccups.

5.2.2.2 Social acceptance

Only do construction outside the winter period. Especially in cold climate countries this is an important general best practice. Only do construction outside the winter period and ensure that people can get heat and water from other sources if the disruption takes more than a day.

Co-ordinate with utilities to cause less disruption. Again we come across the general best practice of working and co-ordinating with utilities. When working together with utilities, the total amount of disruption is lower.

Execute project in phases to minimise disruption to normal city life. This general practice mainly holds for big projects and cities. It can be hard to install large pipes in small roads. To do so, the roads need to be closed for traffic. In Milan the coupling of the small networks was executed in phases. By doing it in this way only some streets had to be closed for traffic at the same time. The disruption of traffic was handled separately for each part of the network. All the construction works were planned and there was co-ordination with the local police. The importance of this general best practice depends on the place of construction. In a big city it is important to take it into account, while in a small village it is less important.

5.2.2.3 Other strategic items

Have regular co-ordination meetings. By having these meetings regularly, everyone is informed and up to date on the progress of the project. This can smoothen the collaboration during the construction phase.

Put more time in the project to create bonds with partners for future projects. This general best practice is focused on the current project and future projects. By putting more time in, trust is created among all those involved, which makes co-operation in future projects easier.

6 Validation from stakeholders across the European Union

The best practices were extracted based on eight cases. This chapter addresses whether the findings are perceived as representative by many different stakeholders working on DH across the EU (and for the survey outside the EU as well). In this chapter two tests of the findings will be presented. First a short summary of a workshop (plenary discussion meeting) TNO and DHBD organised with the interviewees will be given, followed by the findings from a questionnaire sent out to more than 4 000 persons worldwide with an interest in district heating.

In addition, a webinar has been organised to share and discuss the results. More than 60 experts throughout the EU attended this webinar. The findings were similar to the two tests described below.

Validation with the interviewees of the selected cases

Both tests confirmed the findings in the report and had nearly nothing to add to the best practices identified both for the planning and construction phases. The first test – a workshop with the cities involved confirmed that the team had identified as the correct best practices from the eight selected cities. Whereas the questionnaire going out worldwide to 4 000+ recipients confirmed that the cities selected and the result from the investigation can be considered to be representative beyond the eight cities.

The workshop meeting was held with most of the persons that were interviewed in the eight cities. On the agenda of the meeting was both a short summary of the way the research was conducted (including objectives, methodological approach, overview of case studies, deliverables and dissemination plan) and a more detailed introduction to the findings. The draft report was shared with all participants in the meeting a few days prior. This part was followed by an open discussion of the findings and other topics the group found relevant. First of all the group found the identified best practices correct, maybe with one exception. There were no best practices added to the list, neither was it mentioned that any of the identified best practices were not relevant. The only comment was that not all best practices are relevant for every project, e.g. it was mentioned that the best practice about not digging in the winter months is much more relevant for cities with colder winters. The TNO and DBDH team concluded after the meeting that the message should be that the list of best practices is certainly not a checklist because not all findings are applicable to each case, but rather a strong reference list that especially cities with less experience can use. Stakeholders who use the list may check which best practices hold in their situation and follow them up.

Validation via a large group of contacts worldwide

DBDH used their database of district heating contacts worldwide to send out a survey to get feedback on the best practices identified and to ask if any best practices should be included or excluded. In total 62 people answered the questionnaire out of 4 000+ recipients of the email. We asked how important the respondents found each of the best practices on a scale from 1-5, ranging from 1 = Not important to 5 = Very important. The team did not use complex statistical analysis tools to interpret the results, but simply looked at the average score. Only one question received a really low score. That was the best practice “Only do construction outside winter period” with a score of 2.8. All other best practices received a rating between 3.7 and 4.7, with the highest being “Have a long term heat strategy” with a score of 4.7, and the lowest being “Involve the local population during the planning phase” and “Take away the investment barriers for customers, e.g. by leasing the heat delivery set” with a score of 3.7. The team also asked for further comments and best practices in a free text format. Here the team received a series of details about specific countries and their situation as well as some positive replies about both the study and the identified best practices – in short not any replies that affected the results. The division of respondents by stakeholder type can be seen below.

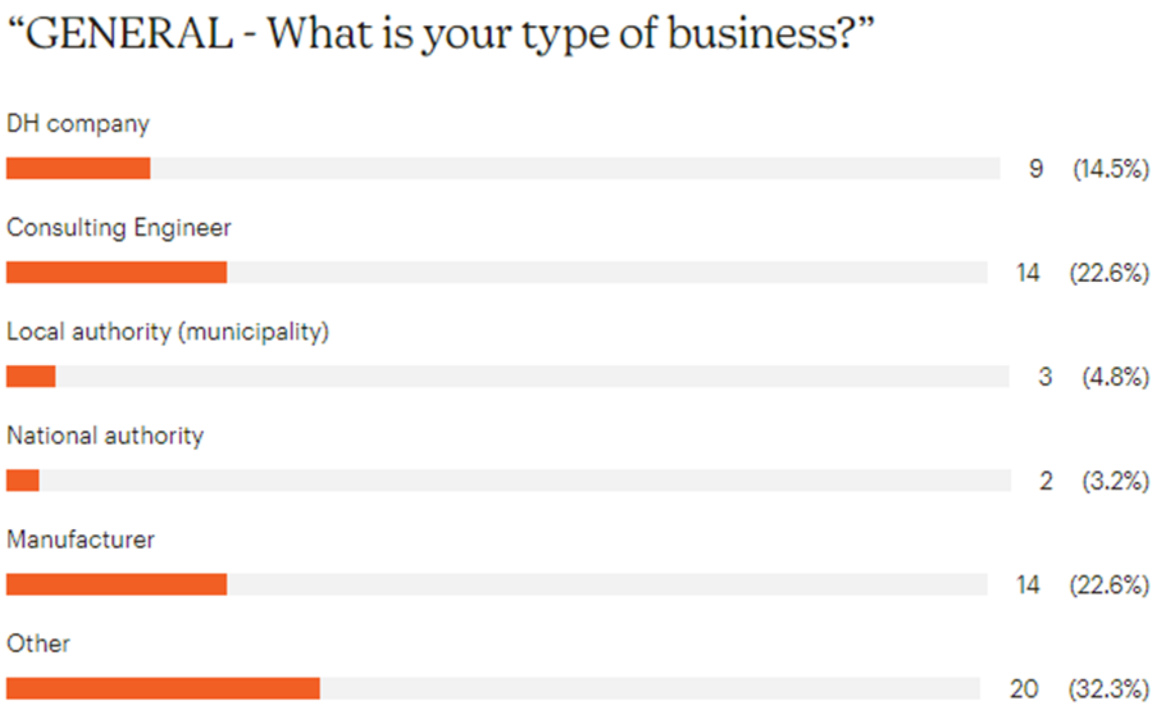

Figure 15. Type of business answering the questionnaire.

7 Conclusions including guidelines

This report contains the analysis of a series of interviews conducted with eight district heating companies and associated municipalities in the EU. The purpose of this exercise was to identify best practices in the planning and construction of district heating networks in the existing built environment. These eight cases are as diverse as possible to collect best practices from a wide variety of district heating projects.

Based on the interviews many best practices have been identified. Some of these are relevant only for a specific situation and under specific framework conditions, but many are more general and are applicable to multiple types of projects. Through a cross-case analysis, we have distilled the *general* best practices into five categories: business case and costs, governance, social acceptance, regulation, policy and subsidy, and a group of other strategic items. Besides, a distinction has been made between best practices during the planning phase and ones during the construction phase. These best practices should hold for most projects throughout the EU. Of course, which best practices are most relevant will vary across projects, municipalities and countries. Also, the experience of the municipality and the DH company will influence which best practices support the project at hand the most.

The most important best practices are summarised below, first for the ones in the planning phase and then the ones during the construction phase. The best practice can be boiled down to maybe one mentioned by almost all interviewees: “Do your planning very well and include all relevant parties in a constructive process. Then construction will be easier, and the best system will be in place”. This might oversimplify the main result, but at the same time demonstrates how important the planning phase is in creating a successful district heating project.

Planning phase – business case and costs

Start planning with large consumers as this positively influences the business case. In most cases it will also be easier to expand the thermal network to the other parts of the area. To avoid the risk of too little demand, district heating companies usually have an entry level. By starting with large consumers, it becomes easier to reach the entry level of heat demand to be contracted and construction can start sooner.

Focus on locally available renewable energy or waste energy sources. To move towards more sustainable ways of heating in the built environment it is important to invest in heating options that are available, have security of supply and cause less emissions. A regional potential assessment helps to identify these heat sources. Utilising relatively nearby resources can contribute to reduced heat production costs and therefore be beneficial for the business case.

Work together with other utilities. When working with other utilities, such as sewage or electrical, the costs can be distributed over the different projects, such that the costs per project are lower. However, it is not always possible to work together with other utilities, or do it in a cost-effective way. If the planning of the two construction works do not fit together it can actually increase costs instead of decreasing them.

Have a clear risk and responsibility package from the beginning. There will be hiccups during the construction phase and clear agreements made during the planning phase can avoid disagreements and problems during the construction phase.

Visualise the business case from the start, including what a change in conditions will do. Start with a business-as-usual business case. This should create an overview of the heat demand in an area in the beginning to determine whether district heating can be an economic solution. Uncertainties during the planning phase and changes in condition will affect the business case.

Planning phase - governance

Have a long-term heat strategy. Municipalities (and operators) should define a long-term heat strategy as this provides the dot on the horizon e.g. in 30 years from now, which then can be translated to concrete actions and plans in the present.

Have an overview of public buildings with a large energy demand. This relates to the best practice of start planning with large consumers mentioned above. An inventory can also show when renewals of heat systems of these public buildings are scheduled.

Planning phase - social acceptance

Communication prior, during and after project execution with local stakeholders. It is important to communicate clearly with local stakeholders, including the general public. This should be done prior to the project (informing what will happen), during the project (informing the process of the project) and after project execution (to update on the project). This involves informing and educating the local population on energy issues to create enthusiasm for district heating and the project.

Additionally, involve the local population during the urban planning phase. This requires a more active role from the local population. This can create more support for the project from the local population.

Remove the investment barriers for customers. The investment barriers can be taken away or lowered by leasing the heat delivery set. Instead of a single investment, consumers pay a monthly fee.

Planning phase - regulation, policy and subsidy

It is difficult to determine general best practices for this category, as each case comes from a different country, which has a different context of regulation, policy and subsidy. The general best practices mentioned below were mentioned by several cases. They do not prescribe which regulation is best for district heating.

Have a smooth process for approvals from the municipality. Although the role of municipalities differs by case, they normally have a special role in the planning of district heating, i.e. to approve and supply permits. A smooth process for this can save time. An example is to have one contact point between the operator and municipality, such that clear agreements can be made.

Policy should have a guiding role. Local and national policies play a role in encouraging district heating. This can also be regulated, e.g. by not allowing new buildings to be heated by gas. This makes district heating an interesting option.

Use EU support funds to finance projects in relatively low-income countries.

Planning phase - other strategic items

When you lack knowledge or experience, collaborate with (international) partners who do have it. The level of expertise differs across countries, municipalities and projects. For many people involved in projects, district heating is a new subject, and they lack expertise. Involve partners with expertise from the beginning and learn from them so you can execute future projects with less help.

Take your time for the urban planning phase. In many cases the planning phase took a long time. However, this was seen as something positive. Enough time is needed as different ideas from the different stakeholders have to converge and most problems should be solved during the planning phase and before the construction phase.

A transparent process and joint commitment of the stakeholders involved. During this phase understanding and trust should be created between all stakeholders involved. It is important to have clear communication. As a result, everyone involved has the same knowledge of the project and the interests are aligned.

Construction phase – business case and costs

Adhere to the BAT. What the BAT is might differ between projects. It is a balance between investment costs, operational costs and other relevant criteria such as sustainability. Investigate your options and choose the one which is best according to your criteria.

Work together with other utilities. By working together, the costs of construction can be lowered. One must be careful that the planning of the projects can be aligned. Otherwise, this can raise costs instead of decreasing them.

Lower the temperature to increase efficiency. A lower temperature results in a more efficient district heating network, as the heat losses are lower. This influences the design of the network and on the choice of heat sources.

Be prepared for hiccups. During the construction phase hiccups will almost surely occur. This also relates to the general best practice in the urban planning phase to create a clear risk and responsibility package. This package can help during these hiccups.

Construction phase - social acceptance

Only do construction outside the winter period. Especially in cold climate countries this is important. Ensure that people can get heat and water from other sources if a disruption takes more than a day.

Co-ordinate with utilities to cause less disruption. Again, we come across the best practice of working and co-ordinating with utilities. This will lower the total amount of disruption.

Execute the project in phases to minimise disruption to normal city life. This mainly holds for large projects and cities. For example, it can be hard to install big pipes in small roads.

Construction phase – other strategic items

Have regular co-ordination meetings. By doing so, everyone is informed and up to date on the progress of the project. Besides, it can smoothen the collaboration with other stakeholders during the construction phase.

Put more time into the project to create bonds with partners for future projects. This enables creating trust among all those involved, which makes co-operation in future projects easier.

Guidelines

The list can be used almost as a checklist. But not a checklist where all points have the same relevance for all situations. So, evaluate the importance of each best practice for your project.

This guideline was also confirmed during the workshop with all the interviewees. The list of best practices can ensure a successful project, when used as a reference list that especially cities with less experience can use and will help them in having a smoother and better planning and construction phase. Another conclusion was that the list can be used to identify and select the best practices that are most suitable for a specific project. Not only at the beginning but to be reassessed regularly, to check if these are still the most relevant ones, and to adjust the project accordingly.

This report highlights a series of best practices that all district heating projects can benefit from using. The research also showed that good, careful planning is essential. Some even said that planning is the only best practice needed. The report also points towards further research valuable for future district heating especially regarding planning. Better insight into good planning cases, planning methodology and planning legislation could potentially help EU cities and district heating companies reach their goals in better, less expensive and faster ways.

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List of abbreviations and definitions

BAT	Best Available Technology
DH	District heating
EU-ETS	European Union Emissions Trading Scheme
HT	High temperature
LT	Low temperature
NECP	National Energy and Climat Plan
Waste heat	In this report waste heat is used in line with EU legislation and statistics. This is also known as residual heat. We further distinguish cogenerated heat, which is the heat produced by Combined Heat and Power systems (CHPs).

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Appendix A: Questionnaire

Before an interview an email with introductory questions was sent to the interviewee. During the interview a questionnaire was used to structure the interview. This questionnaire consists of key questions and check questions. The focus of the interview was on the key questions. During the answering of these questions, most of the check questions were answered as well. If a certain topic seemed especially relevant for a case, the check questions could be used to get more information on this topic. If a topic seemed not relevant, then these questions could be skipped. The questionnaire is split into a planning and construction phase part and follows the categories as used in the report.

A.1 Email sent before the interview

This questionnaire will support the collection of information of the cases and leads to a better understanding of successes and failures of the development of thermal networks in existing residential and service sector areas.

Questions about **key facts of the project** to be asked by email **prior to the interview**. These questions will serve as background information and will guide the interviewers to the group of questions that seems to be most relevant for the interview about the project. “Project” is defined as the combination of planning and construction of a district heating system.

Questions that need to be answered:

- Can you describe the supply chain of your thermal network and the ownership of the different stages?
- Can you describe the finance structure of this network?
- What is the policy when new heat resources are available in the area? Are they able to supply to the network? Is there a merit order for supplying heat to the network?
- From your perspective, what are the 3 key elements that have made your project a success?
- If any, what bottlenecks did you encounter during the planning and/or construction phase of your project? And what is needed to prevent these bottlenecks in future projects?

Questions of which answers are nice to have (answers to the first two questions are already collected during case selection):

- Does the project concern a new standalone project or an extension to an existing network?
- What are the main location characteristics? (e.g. heat density? Old city center?).
- Which types of main heat source(s) are included? (To be built? Existing sources on location or external?).
- Which types of back-up heat sources are included?
- What kind of heat storage/buffer is included?
- What are the emissions in CO_2/MWh heat supplied?
- How many connections (dwellings vs non-residential) and how much heat supply (MWh) per year?
- Can you provide a map on which the layout of the district heating system is visualised?
- What are the average tariffs for residents (based on average heat consumption per dwelling)?
    - How do these tariffs compare with the tariffs of alternative heat sources?
    - What is the structure of the total price – fixed, variable fees, connection fees, penalty/benefit for good/bad cooling?
    - Do you apply differentiated prices for different customers?

A.2 Questionnaire

Questions about the ***planning*** phase:

	Key questions	Check
	About the person	
1	What was your role in the planning phase?	What was your knowledge of DH planning when you started this project? Are the specific part of the planning process you find crucial to creating a success? Can you elaborate on the success factors during the planning phase? Ditto on your lessons learned, i.e. what will you differently in the next project?
	Costs and tariffs	
2	Please describe the planning phase of this project. What was easy, complex, took (way) more **time** than scheduled, **cost** more or less?	What are the benefits of your planning method? How much time was involved between first idea and approval of the plan? How much time and effort has been spend on different stages of planning? Who were involved in the preparatory discussions and at what stage of the project? And what role did each of them play? Decision, advice, influencer, expert? And how did you organise stakeholder management? How was the area for the thermal network identified? • Heat mapping. • e.g. existing waste heat from industry, renewable source. • Neighbouring heat networks to connect to. Based on which planning tool. How would you describe your project: based on long-term experience, state-of-the-art, innovative? Estimate time (and money) spent on different aspects of preparation. E.g. • Develop project idea • Communication with stakeholders incl customers • Make feasibility study • Project definition • Develop business case • Procurement • Permits How complex/easy was each phase? Can you elaborate on the balance between heat mapping, technical feasibility and economic viability planning? How did this connect to the overall spatial / urban planning in the area? Were tariffs promoting more sustainable use of energy used? e.g. bonus/malus
	Governance	
3	Is there a **long-term strategic heat plan** (of the municipality, the utility, the...)?	Describe the local heat planning policy, e.g.: • How has the heat plan been developed and updated and how often?

	How much knowledge should be 'in-house'? (e.g. a city who wants to build a DH grid?) Which knowledge would you recommend to have in-house?	• Was there competition between different alternatives, and if so, how did this look like? • Did the planning include external factors, e.g. pollution, job creation, fuel poverty? • Is there an obligation to connect to the network? • Are there stay-on clauses, what is the length of contracts? Why was district heating chosen, and what are the main advantages of this solution compared to other heating alternatives (e.g. decision based on building density, insulation level of houses, presence of heating source etc.)?
4	How has the decisions been made on **ownership**, business model, and time horizon of investment? And how is the structure today, i.e. who owns, control, finance?	
	How did the DH project fit into the **spatial / urban planning** policies?	In what way did spatial / urban planning support / jeopardise the development of the DH project? What connections with other policy domains needed to be made?
	Social acceptance	
5	To what extent have **customers** been involved? Were the customers open for district heating, or did you have to persuade them? How were customers persuaded to participate? How are vulnerable customers (e.g. low-income) treated?	E.g. energy/gas companies, industries with waste heat, large heat users, local government, other authorities, citizens, etc. Communication prior, during and after project execution with local stakeholders Did the (local) government provide support e.g. by setting aside money and time to investigate in the project? How many customers participated and why, or why not? At what moment did you start to make contact? And ditto for the contracts, e.g. to connect already at an early stage? Was there a difference in participation between different kinds of customers? Existing buildings
	Other	
6	To what extent has the future been taken into account (e.g. better **insulation** and **expanding** the network)?	Is there a programme for insulating buildings in the area? If so, in which way was the fact that buildings will be better insulated in the future considered? Has the project been made to measure – or is there room to grow? Did you continue approaching customers in the construction phase – and did you succeed? Are there plans to expand the network further in the future? If yes, are they already considered in the

		planning of this network? And in the design of essential part of the network? Do you have any considerations to expand towards larger heat sources or larger base-loads? Was a technology/fuel shift considered in view of future energy policies?
		How was the inventory of heat demand and supply established? Did one strive for diversity of heat loads and heat sources to smoothen supply and demand in space and time? Are there stimuli to adapt demand to supply? How were the optimal pipe routes determined considering obstacles like roads, railways? Explain the underground organisation and planning for existing and new infrastructure in the area, e.g. water pipes, electric cables, reserved lanes for heat pipes, etc. Was there co-ordination with other street works (either repairs in the street or new construction) and other infrastructure e.g. new optic fibre, water network, electricity network etc. during the planning phase?

Questions about the ***construction*** phase:

	Key questions	Check
	About the person	
1	What was your role in the construction phase?	Are the specific part of the construction process you find crucial to creating a success? Can you elaborate on the success factors during the construction phase? Ditto on your lessons learned, i.e. what will you differently in the next project?
	Costs and tariffs	
2	Please describe the construction phase of this project. What was easy, complex, took (way) more **time** than scheduled, **cost** more or less? Did the time and cost of construction correspond with the time and cost foreseen in the planning phase?	Can you tell us about the execution compared to your original schedule and budget? E.g. did you experience severe delays, cost overruns in the construction phase due to missing planning? What was the estimated time (and budget) spent on different aspects of the construction phase, e.g. • Preparatory work • Construction of grid • Realising dwelling connections
	Governance	
3	What **methods** or **technologies** were used in the preparatory construction work and construction phases of the grid? And how was the construction phase **organised**, including quality control? What was the role of the local authority during the construction?	Who made the final design? Who was the owner engineer (controlling the construction based on this design etc.)? How was quality control organised? Can you describe how disputes were solved? How many contractors were involved in the construction? How were they organised in terms of legal structures, e.g. yes/no main contractor, role of your organisation? What was the type of contract, e.g. Design-Build, Design-Build-Maintenance? Can you describe the layout and main components of the district heating system (on the DH layout map)? (Have any innovative components, processes or designs been incorporated?) Indicate the time needed for installation of the main transport grid and/or distribution grid? Ditto for connecting the houses to the distribution grid?
	Social acceptance	
4	How did one **minimise disruption** to normal city life? And how? E.g. close only one street at the time? Work during certain periods or times in the day?	Which barriers have been encountered in this phase, and how were they overcome?
	Other	
5	Did one employ any **innovative** technologies for the construction, e.g. drilling techniques, measurements, new types of piping?	Did you need to arrange additional measures e.g. with regards to quality control?

Questions about ***policy stimulation and tariff regulation in the country***:

	Key questions	Check
1	Which **policies** had an effect on this project?	Either national or local policy. Either in facilitating or being a barrier.

	To what extent have **subsidies** been made available?	For what part of the costs of your project are the subsidies used? What other policy stimulation measures have been in place / applied? [Here also the perspective of spatial / urban planning and relation to other policy domains can be brought forward]
2	How are the **tariffs** determined?	E.g. determined per network or national. Is there any regulation about heat tariffs and/or the transparency? (Accounting rules and/or benchmarks?) Are the tariffs based on the costs of the project, are they capped or are there other measures influencing the tariffs? Which components are included in the tariffs and what is the height? (e.g. connection costs, fixed costs, variable costs) (in €/year and €/kWh). Was thought put into the future of tariffs in the planning phase?

Questions to ***finalise the interview***:

	Key questions	**Check**
1	Did the project deliver as you expected?	What can be improved, and how?
2	What were the biggest surprises in the planning and construction phase?	What can you recommend to others to prevent these surprises?
3	Based on your experience today – what best practices would you like to have known before you started on this project?	

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