AALBORG UNIVERSITY

Master Thesis in Sustainable Cities

Transition in the Making

Examining the Transition Process of Lowering the Supply Temperatures of Existing District Heating Grids in Six Case Municipalities in Germany

Project Period:	Spring Semester 2021
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Page Number:	100 (excluding Summary)
Date of Completion:	July 29, 2021

Foreword

The Master thesis is written during the 4th semester of the Master programme Sustainable Cities at Aalborg University. District heating based on renewable and excess heat is a key technology to decarbonise space heating and domestic hot water preparation in densely populated urban areas. In my last semester project, I examined Germany's key political, economic, social, technical, legal, and environmental drivers and barriers for significantly increasing district heating, mainly using renewable and excess heat. Nationwide, the lack of central actors conducting heat planning at the local level and the high temperatures of many existing district heating grids are identified as key barriers. The idea of this Master thesis is thus, to study how the process of lowering the temperatures of existing DH grids is structured in selected case municipalities, focusing on the DH operator as operator of the system and the climate protection department as the coordinator between the various actors.

I would like to express my gratitude to all my interview partners for taking the time to answer my questions. Without them, the Master thesis would not have been possible in this way. I would also like to thank my supervisor, Associate Professor David William Maya-Drysdale, for providing valuable insights and constructive feedback that helped shape the thesis's content.

Summary

DH, mainly supplied by various renewable and excess heat sources, is a key technology to decarbonise the space heating and domestic hot water preparation in densely populated areas. However, many existing DH grids in Germany are mainly supplied by fossil fuels and have high supply temperatures, leading to significantly higher heat losses and hampering the integration of renewable and excess heat sources. Lower supply temperatures enable a more cost- and energy-efficient integration of locally available renewable and excess heat sources and limit the usage of biomass and synthetic fuels. However, the organisation of the energy and heating system is aligned to the current fossil fuel-based energy system, requiring structural changes in the organisation of the systems. For lowering the temperatures of existing DH grids and switching to renewable and excess heat sources, the available local heat sources, grid aspects, and the customer side need to be considered. For reducing the supply temperature, the mass flow needs to be increased, requiring simulations for the individual DH grid to identify possible bottlenecks and critical components due to the pressure increase, the return decreased, or both. By first reducing the return temperature and then the supply temperature, the thermal capacity of the DH grid remains the same. The return temperatures and the ability to reduce the supply temperatures depend on the design parameters of the installed substations and heating systems in the buildings and their operation. For reducing the supply temperatures, all buildings connected to (the part of) the DH grid in which the supply temperature is to be lowered need to be able to use these lower supply temperatures, requiring a strategic, coordinated approach. Besides the customers and the DH operators, municipalities are key actors in the transition, enabling coordination between the DH operators, housing associations, numerous individual building owners, and various other actors involved in the transition. Due to the diverse framework conditions regarding organisational and technical characteristics, the process needs to be tailored to the local context. For this, multiple case study is used as a research design in the Master thesis to analyse the transition process in their real-life context, namely in Frankfurt am Main, Henningsdorf, Jena, Potsdam, Rostock, and Springe. The transition process is analysed, taking transition management as a theoretical framework for how multi-actor processes can be structured to overcome lock-in and reach sustainable development. For this, data is collected by analysing existing documents and conducting 12 semi-structured interviews with practitioners from the DH operator and the climate protection department located in the case municipalities.

For the case municipalities, heating concepts were or are developed through funded projects or to comply with the legal obligations. Due to the long technical lifetime of the heating facilities and substations, it is crucial to determine the future temperature levels now. Potsdam and Jena have identified long-term targets for reducing the supply and return temperatures,

requiring the adaptation of the substations and possibly the heating systems in the buildings. The technical connection conditions were adapted, and the determined future temperature levels included installing new substations with these new design parameters and replacing existing ones as part of the regular renewal cycle. However, the concept in Jena does not include the building side due to a lack of data. In Henningsdorf, for reducing the supply temperature to 95°C by 2022, site visits are conducted to obtain data on the temperature level and adjust the operation of the substations to lower supply temperatures. For Frankfurt am Main, Rostock, and Springe, concepts to lower the temperature levels of the DH grids in the long term are to be developed. In Springe, the aim is first to connect the buildings to the DH grid, lower the ST using existing funding programmes, and develop a strategy for lowering the RTs.

For incentivising lower return temperatures, Frankfurt am Main, Jena, Potsdam, and Rostock have implemented basic prices depending on the maximum flow passing through the substation and have or have plans to implement return temperature-dependent tariffs. In Henningsdorf, Jena, and Rostock, the DH operators offer heating services, providing them access to the substations and the opportunity to operate the heating systems in the buildings with lower temperatures as the radiators are generally oversized.

For informing and advising the building owners on energy-efficient refurbishment measures, all DH operators offer energy consulting services, and in the larger cities also the Consumer Centres. In Frankfurt am Main, a non-profit organisation provides independent, free-energy counselling, and in Springe, the redevelopment manager.

In Frankfurt am Main, Potsdam, Rostock, and Springe, the district level is emphasised as an essential planning level, enabling to concretise targets for the whole city, develop and implement models and technical solutions, test new participation formats, generate synergies by integrating other aspects and establish organisational structures. In Frankfurt am Main, Potsdam, and Rostock, the experiences gained in the districts are to be used in similar projects in the city.

For a successful transition, more personnel resources and reliable framework conditions aligned to the goal of climate neutrality are seen as crucial by the practitioners. Furthermore, developing new ways of financing and finding new ways to approach and involve the actors better is seen as essential.

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List of Abbreviations

AAU	Aalborg University
BAFA	Federal Office of Economics and Export Control
BBSR	Federal Institute for Research on Building, Urban Affairs and Spatial Development
BDEW	Federal Association of the Energy and Water Industry
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BMWi	Federal Ministry for Economic Affairs and Energy
CHP	Combined Heat and Power Plant
dena	German Energy Agency
DH	District Heating
DHW	Domestic Hot Water
EWP	Energie und Wasser Potsdam
GHG	Greenhouse Gas
ICT	Information and Communication Technology
IRENA	International Renewable Energy Agency
KfW	Credit Institute for Reconstruction
RT	Return Temperature
SH	Space Heating
ST	Supply Temperature
SWEJ	Stadtwerke Energie Jena-Pößneck
SWH	Stadtwerke Henningsdorf
SWJ	Stadtwerke Jena
SWJN	Stadtwerke Jena Netze
SWP	Stadtwerke Potsdam
SWR	Stadtwerke Rostock
SWS	Stadtwerke Springe
TABs	Technical Connection Requirements
TEAG	Thüringer Energie AG
UBA	Federal Environmental Agency

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1 Problem Area

The following section will outline the general context of the Master thesis and present literature relevant for lowering the supply temperature (ST) of existing district heating (DH) grids, leading to the research question, scope, and structure of the Master thesis.

1.1 District Heating Systems in the Future Energy System in Germany

Germany has set the target to become climate-neutral by 2045 (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), 2021). In 2018, around 84% of all greenhouse gas (GHG) emissions in Germany were energy-related, making fossil fuel combustion the main driver of climate change (Federal Environmental Agency (UBA), 2020). Reducing the GHG emissions stemming from the combustion of fossil fuels requires a transition, a radical change, of the energy system (Federal Ministry for Economic Affairs and Energy (BMWi), 2020; Geels, 2005).

Heating is the largest energy consumption sector, accounting for 54% of final energy demand in 2018, with 23% stemming from process heating and 31% from providing space heating (SH) and domestic hot water (DHW) (Federal Association of the Energy and Water Industry (BDEW), 2020). To decarbonise SH and DHW preparation, measures on the demand and the supply side are necessary (Maaß et al., 2021). In comparison to electricity and gas, heat cannot be distributed or exchanged over long distances, requiring heat planning at the local level (Thamling et al., 2020). Energy scenarios developed by Agora Energiewende, BDEW, the Federation of German Industry, Fraunhofer IEE, Fraunhofer ISE, Heat Roadmap Europe, Prognos, and UBA show that energy-efficient refurbishment of buildings and DH grids supplied by in average over 92% renewable and excess heat sources in densely populated, urban areas are key technologies to achieve 80-95% GHG reduction by 2050 compared to 1990 levels[1] (Maaß et al., 2021; Paardekooper et al., 2018).

DH grids enable the integration of various decentral renewable and excess heat sources, complementing and competing with each other to meet the highly varying heat demand, as seen in Table 1 (Maaß et al., 2021).

[1] 80-95% GHG emission reduction represents the former goal set by the German government (BMWi, 2020)

Table 1: Operating characteristics of renewable and excess heat sources

Heat Sources / Technologies	Advantages	Disadvantages
Geothermal	Continuously available (International Renewable Energy Agency (IRENA) & Aalborg University (AAU), 2021)	Competes with excess heat and solar thermal for base load production (Paar et al., 2013)
Solar Thermal	Available almost everywhere (IRENA & AAU, 2021)	Heat production takes place mainly in summer when the heat demand is lowest (Danish Energy Agency & Energienet, 2020)
Biomass/ Synthetic Fuels	Very flexible operation with fuel storage infrastructure => possible to supply peak load (Danish Energy Agency & Energienet, 2020; Maaß et al., 2021)	Limited availability => should be prioritised for decarbonizing other sectors (Hansen et al., 2019)
Excess Heat	Use of an otherwise lost resource (IRENA & AAU, 2021)	Availability depends on location, temperature level, and continuity of process (Maaß et al., 2021)
Heat Pump	Very efficient operation, increases the temperature of heat sources by converting one unit of electricity into 2.7 to 6.5 units of heat (Hennessy et al., 2018)	Requires heat sources of sufficient size, stability, and temperature to operate efficiently (Helin et al., 2018)
Electrode Boiler	Very flexible operation, can convert excess electricity into heat (Eller, 2015)	Low efficiency compared to heat pumps (Danish Energy Agency & Energienet, 2020)

For the electricity sector, current-regulated combined heat and power (CHP) plants and Power-to-Heat facilities combined with large heat storage in DH grids is seen as one of the most needed flexibility options for the energy transition in Germany (Eller, 2015).
Besides decarbonisation, DH grids based on renewable and excess heat reduce air pollution and promote regional value creation (IRENA & AAU, 2021). From each € the customer pays for DH using mainly biomass and waste, around 0.7 € remain in the municipality - compared to only 0.25 € for natural gas (Besl & Eikmeier, 2015).

DH grids generally depend on comparatively high heat demand, making heat demand reductions and DH seemingly incompatible, competing strategies (Schubert, 2016). Low-temperature DH grids combine these two strategies, supplying SH and DHW from low-temperature renewable and excess heat sources with low distribution heat losses to existing, energy-renovated, and new low-energy buildings (Lund et al., 2014).

1.2 Current District Heating Systems in Germany

In Germany, however, the current rate of energy-efficient refurbishment is only 0.8%, and only 10% of the heat demand for SH and DHW is supplied by DH (BDEW, 2020; Freudenberg et al., 2019). Fossil fuels still dominate DH with only 6% excess heat and 15% renewable heat (AGFW[2] et al., 2020). 72% of the heat is generated in CHP plants (German Environmental Aid, 2021). These CHP plants are often operated with maximum annual operating hours and a low orientation towards the electricity market. As a result, the base load is often covered by subsidised heat from fossil fuel-based CHP plants, displacing renewable and excess heat. (Sieberg et al., 2016)

Every DH grid is unique regarding thermal capacity, fuel usage, and operating temperatures (Triebs et al., 2021). There is no publicly available database known listing the DH grids and their operating parameters in Germany (AGFW et al., 2020; Geiger et al., 2021). Most common are DH grids with a supply temperature of 90 to 140 °C (Paar et al., 2013).
Such high temperatures lead to significantly higher heat losses in the DH grids (Averfalk & Werner, 2020). The heat losses in the DH grid contribute a significant share to the annual operation costs and profoundly increase the resources used to provide the heat (Li et al., 2017). For feeding heat into the DH grid, the heat must comply with the grid's technical conditions like pressure and temperature level (German Energy Agency (dena), 2019). From a technical perspective, it is far easier to replace fossil fuels with synthetic fuels and biomass to integrate renewable heat (Deutsch et al., 2019). As stated above, the availability of synthetic fuels and biomass, however, is limited. The usage of these fuels should, thus, only be used to provide peak load that could not be covered by other heat sources and prioritised for sectors where only a few alternatives for decarbonisation exist (Hansen et al., 2019; Maaß et al., 2021). Lower STs of the DH grid allow the integration of a broader range of heat sources and enable more cost- and energy-efficient integration of locally available renewable and excess heat sources (Averfalk & Werner, 2020; IRENA & AAU, 2021; Leoni et al., 2020). Table 2 shows the benefits of operating temperatures of DH grids to integrate renewable and excess heat sources.

[2] The German District Heating Association

Table 2: Advantages of lower operating temperatures for integrating renewable and excess heat sources in DH grids

Heat Sources/ Technologies	Advantages of Lower Operating Temperatures
Geothermal	Low- and medium-temperature sources are more widely available than high-temperature sources (IRENA & AAU, 2021), plants are much easier to build (Lund et al., 2014), and significantly more heat can be extracted from the same geothermal site (Averfalk & Werner, 2020; Sandrock et al., 2020)
Solar Thermal	Significantly more heat can be extracted from the same solar collector (Rämä & Sipilä, 2017)
Condensing Boilers	More heat can be recovered from the energy carrier used (Lund et al., 2014)
CHP Plants	More electricity can be generated from the energy carrier used (Lund et al., 2014)
Excess Heat	Higher potential as low- and medium temperature sources can be integrated directly if the heat source is higher than the DH grid, or more efficiently using a heat pump to boost the temperature of the heat source (Lund et al., 2014 & 2017), and significantly more heat can be extracted from the same heat source (Manz et al., 2021)
Heat Pump	Higher potential as commercially available technologies and low- and medium heat sources can be used (Sayegh et al., 2018), and less electricity input is necessary to increase the temperature of the heat source (Lund et al., 2014)

1.3 Lowering the Temperature of DH Grids is a Complex Process

Lowering the temperature of existing DH grids and integrating renewable and excess heat sources is a complex process, requiring - as experiences from Denmark show - long planning periods (Onischka et al., 2018). Transition strategies need to take the amount and temperature level of available local renewable and excess heat sources, grid aspects such as transport capacity of and bottlenecks in the pipelines, and the customer side, like contracts, DH substations[3], installed SH and DHW systems, heat demand, and energy efficiency of the building, into account (Averfalk et al., 2017; Deutsch et al., 2019; IRENA & AAU, 2021).

Pressure, ST and RT, are the main operating parameters of a DH grid, determining the thermal capacity that can be transferred within the DH grid (Paar et al., 2013). The thermal capacity of the DH grid can be calculated with the formula $\dot{Q} = \dot{m} * c_p * (ST - RT)$, with $\dot{m}$ being the mass flow and c_p being the thermal capacity of water (Paar et al., 2013). Accordingly, increasing the

[3] DH Substations connect the DH grid with the installation of the customers (IRENA & AAU, 2021)

mass flow and decreasing the RT enables to lower the ST while providing the same thermal capacity (Paar et al., 2013). The mass flow can be increased if the pipelines are oversized due to widespread heat demand reductions, for example, or by increasing the volume flow (Schöttke et al., 2016). As the pressure drop is proportional to the square of the flow velocity, increasing the volume flow results in a considerable pressure drop (Paar et al., 2013). This pressure drop could become higher than the maximum pressure the pumps can compensate, or higher than what the pipelines can maximally withstand, or both (IRENA & AAU, 2021). For this, simulations must be carried out for each DH grid to identify critical components that must be replaced to operate the DH grid with the new pressure level. (Paar et al., 2013).

By decreasing the RT, the ST can be lowered by the corresponding amount, making the reduction of the RT the first step in the transition to lower temperature levels in existing DH grids (Østergaard & Svendsen, 2019; Averfalk et al., 2017). RT and the ability to reduce the ST depend on the design parameters of the installed substations and SH and DHW systems in the buildings as well as their operation (Dalla Rosa et al., 2014; Paar et al., 2013). Not (correctly) hydraulic balanced heating system and design and installation faults of heating systems, substations, and the distribution network, wear of components higher RTs (Averfalk et al., 2017; Leoni et al., 2020; Østergaard & Svendsen, 2019). For lowering the RTs, the heating systems need to be hydraulically balanced correctly, substations need to be implemented correctly using a heat exchanger with a greater thermal length, and faults of heating systems, substations, and distribution network corrected (Averfalk et al., 2017).

For lowering the ST, *all buildings* connected to the DH grid need to be able to supply SH and DHW using lower ST (Leoni et al., 2020). For this, it is possible first to lower the ST in parts of the DH grid, developing secondary DH grids [4] with a lower ST (IRENA & AAU, 2021; Paar et al., 2013). For lowering the ST, substations need to be designed for lower STs and RTs using a heat exchanger with a greater thermal length. Radiators installed in new buildings are designed for ST of 55 °C, floor heating in new buildings can use ST of around 25-30°C, and older floor heating systems need maximum ST of up to 50-60°C. Older radiators require higher temperatures. Heating systems are often over-dimensioned, making it possible to lower the ST below the design temperatures (Østergaard & Svendsen, 2019). For preparing SH systems in existing buildings without floor heating systems for significantly lower ST, the heat demand of the building needs to be reduced and the heat distribution hydraulically balanced, or larger or additional radiators installed inside the building (Dalla Rosa et al., 2014; Averfalk et al., 2017). For the preparation of DHW, DHW storage units placed at the side of the DH grid and instantaneous heat exchanger units can be used. For avoiding the risk of legionella, DHW storage units need to be heated to 60°C. For small DHW systems and flat stations installed in

[4] Secondary DH Grids are hydraulically connected to the Primary DH Grid (the main grid), making it possible to use the RT and ST of the primary DH grid using as well as own heat sources (Paar et al., 2013)

each apartment with water content below 3 l in the distribution pipelines, instantaneous heat exchanger units with greater thermal lengths require ST of the DH grid of at least 50°C at the customer to maintain thermal comfort. For lower ST than 50 or 60°C at the customer, treatment methods to avoid the risk of legionella or electric heater to increase the ST individually are necessary. (Afervalk et al., 2017)
In the case the heating system of a building is not adapted to lower STs, the ST needs to be increased for the building using individual heat pumps that have higher investment and operation costs than heat exchangers (Leoni et al., 2020; Neirotti et al., 2018).

Technology can be seen as part of a socio-technical system, co-evolving with institutions, societal actors, and policies (Geels, 2005; Goldthau, 2014). Established socio-technical systems "*are shaped and promoted by, and in turn have shaped, existing legislation, regulation, public perception, knowledge and understanding, as well as the technical setup of the infrastructure*" (Djørup et al., 2019, p. 14). For the transition to lower temperatures DH grids using renewable and excess heat sources, structural changes in how these socio-technical systems are organised need to occur (Edomah et al., 2017; Loorbach, 2007). For lowering the temperatures of existing DH grids and using renewable and excess heat sources, a coordinated strategic approach, taking both the supply and demand side into account, is necessary (Krog et al., 2020).
DH operators as operators of the system and the building owners responsible for implementing measures at the building side are key actors for the transition (Riechel & Koritowski, 2016). For the integration of consumers in the process, Krog et al. (2020) reviewed scientific publications on the topic. They found that only a few papers address how DH consumers could be involved in lowering the temperature of existing DH grids (Krog et al., 2020). In the literature, among others, IT tools displaying and ranking heat consumption, information campaigns on, for example, how to detect and correct faults and how to reduce heating costs, service agreements, payment for optimisation measures, energy-saving contracting, and new tariff structures are considered (Krog et al., 2020; Leoni et al., 2020; Månsson et al., 2019).
Besides the DH operator and the building owners, the municipality is a key actor with the ability to steer the transition by facilitating the process and coordinating between the DH operator, housing associations, numerous individual building owners, and various other actors influencing the transition (dena, 2019; Riechel & Koritowski, 2016). These various other actors can take the role of multipliers, experts, and investors (Riechel et al., 2017). Examples of actors that can work as multipliers are tenant clubs, guilds, civil society, and environmental organisations and examples for experts are craftsmen, consultancy, and universities (Riechel & Koritowski, 2016).

Due to the need for long planning horizons, the dissent on goals, and the distributed control among the various actors to implement the technologies, central planning by governments and market forces are insufficient to lower the temperature of existing DH grids and switch the heat supply to excess and renewable heat sources (Krog et al., 2020; Loorbach, 2007; Onischka et al., 2018; Sovacool et al., 2021) *Transition management* is a governance approach that offers operational guidance on structuring strategic co-creation in complex multi-actor processes to achieve sustainable development (Frantzeskaki et al., 2018). Transition management provides both advice on how to structure and flexibilities to adapt the process to the actors, problems, and context (Loorbach, 2010). Transition management has been applied to a wide field of sectors, including energy and building, in small, medium, and large cities (Frantzeskaki et al., 2018). Riechel et al. (2017) developed a guideline for municipalities on how to structure the process of significantly reducing the heat demand and switching the heat supply to renewable and excess heat sources based on transition managements. As municipalities face diverse framework conditions regarding organisational and technical characteristics, the transition approach needs to be tailored to the local context (Knieling & Lange, 2018; Riechel et al., 2017).

1.4 Research Question

The Master thesis examines the transition process of lowering the ST of existing DH grids to better integrate renewable and excess heat sources, taking transition management as a theoretical lens. As the transition is tailored to the local context, multiple case study is used as a research design to study the process in their real-life context (Knieling & Lange, 2018; Yin, 2018). For this, six case municipalities located in Germany are selected that aim to reduce the ST of the existing DH grids located in their municipality to better integrate renewable and excess heat sources. For these selected, six case municipalities, the Master thesis explores how the transition process of lowering the ST of existing DH grids located in the case municipalities is managed.

Hence, the research question of the Master thesis is:

How is the process of lowering the supply temperature of the existing DH grids located in the six case municipalities managed?

1.5 Scope and Structure of the Master Thesis

The Master thesis analyses how the process of lowering the STs of existing DH grids located in the six case municipalities, in alphabetic order Frankfurt am Main, Henningsdorf, Jena, Potsdam, Rostock, and Springe, to better integrate renewable and excess heat sources is managed. In Frankfurt am Main and Jena, DH grids using steam as heat carrier exist (Mainova, 2021a; Schöttke et al., 2016). For comparing the findings of the individual case studies, the Master thesis focuses on reducing the ST of DH grids using hot water as a heat carrier, excluding the transformation from steam to hot water. Besides supplying heat for buildings, DH grids can also be used to cover the cooling demand of the buildings, using additional technical equipment or the heat pumps installed to increase the ST for individual buildings (Buffa et al., 2020; Schöttke et al., 2016). Due to practical constraints, like time and data availability, the focus of the Master thesis is on DH grids supplying SH and DHW. As stated above, DH operators, building owners, comprising numerous individual building owners and housing associations, and municipalities are key actors in the process (Riechel & Koritowski, 2016). Owing to practical constraints, the Master thesis focuses on the DH operator as operator of the system and the climate protection departments of the municipality as (possible) facilitators and coordinators of the process.

In the following, the structure of the Master thesis is described:

In *chapter 2,* transition management as the theoretical framework of the Thesis is outlined.
In *chapter 3,* the methodology is presented, including multiple case study as research design, document analysis, and semi-structured interviews as data collection methods and concluding with how the collected data is analysed.
In *chapter 4,* the general characteristics of the six case municipalities and the characteristics of the DH grids located in the six case municipalities are shortly described.
In *chapter 5,* the results of the cross-case analysis of the six case municipalities are presented to answer the research question.
In *chapter 6,* the applied theory and methods and the findings are discussed, and recommendations for the case municipalities are derived.
In *chapter 7,* the main findings of the Master thesis are summarised.

2 Transition Management

In the following section, transition management will be presented. In the Master thesis, transition management is used as a theoretical framework to understand how multi-actor processes can be set up and conducted.
Transition management is a theoretical framework developed to analyse ongoing governance processes on overcoming lock-ins and aiming for sustainable development (Loorbach, 2007). As stated in the *Problem Area*, the organisation of the socio-technical system is aligned to the current fossil fuel-based energy system, requiring structural changes for reaching sustainable development, taking both the supply and demand side into account (Djørup et al., 2019; Edomah et al., 2017; Loorbach, 2007; Krog et al., 2020). These structural changes encompass changes in all societal domains, including cultural, economic, environmental, institutional, and technological, influencing and strengthening each other (Rotmans, 2005).

Transition management is based on both theoretical insights from governance and complex system theory and practical experiences and observations of transition processes. Transition management is a selective multi-actor process in which frontrunners who are willing towards and can bring about societal change analyse persistent problems and develop a sustainable long-term vision. In the long term, more and increasingly conservative actors are engaged in the process. Transition management distinguishes four different types of governance activities, namely strategic, tactical, operational, and reflexive. (Loorbach, 2010)

Strategic transition management encompasses thoroughly analysing the persistent problem(s) at the system level and developing a long-term, at least 25 years, sustainable vision in a so-called transition arena (Loorbach, 2007).

Tactical transition management includes translating this long-term sustainable vision into transition paths and building networks to introduce, manage and sustain processes in an expanded transition network. Transition paths contain intermediate, shared goals, joint objectives, and medium-term, five to 15 years, actions necessary to achieve the long-term visions, focusing on structural barriers like regulatory, institutional, economic, technological, and social. The expanded transition network is based on the transition arena including further strategic actors. (Loorbach, 2007)

Operational transition management involves all short-term, in the next five years, actions and experiments derived from the long-term sustainable vision (Loorbach, 2007).

Reflexive transition management is continuously undertaken by monitoring and evaluating the transition itself, the transition process, i.e. the strategical, tactical, and operational activities, and the role of the actors involved. Thereby success factors and reasons for not reaching the goals are identified, the vision and agenda adjusted, and new experiments developed. (Loorbach, 2007)

As stated in the *Problem Area*, transition management provides both advice on how to structure the process and flexibilities to adapt the process to the actors, problems, and context (Loorbach, 2010). In the Master thesis, transition management is adapted to the process of lowering the STs of existing DH grids to better integrate renewable and excess heat sources.

For the *strategic transition management*, the aspects studied include

- political goals, as they either provide the impetus for undertaking analyses on how to reach them or are the outcome of such analyses (BMU, undated; Link et al., 2018),
- investigations regarding locally available renewable and excess heat sources, the current and future heat demand, the energy-efficiency of the buildings, and the future temperature levels of the DH grids, as for the transition, the supply side, customer side, and DH grid needs to be taken into account (Averfalk et al., 2017; Deutsch et al., 2019; IRENA & AAU, 2021),
- and other aspects included in the concepts, as experiences from the district Chemnitz Brühl on the energy-efficient refurbishment of buildings and developing a DH grid with

75°C ST and 45°C RT show that citizens are more interested in the design of public spaces than in the heating supply and as research results indicate that customers seem to be more interested in the thermal comfort and costs than in the heat sources used (German Institute of Urban Affairs, 2018; Sovacool et al., 2021)

For the *tactical transition management*, the aspects studied encompass

- for the transition paths, strategies on lowering the temperature levels of the DH grids, the planning levels identified as being essential for the heat transition, and if applicable, the selection of districts for developing the concepts,
- the organisational structures set up between the key actors (municipality, DH operator, and building owners), including structures for facilitating the process and initial energy consultancy,
- the existence of legal obligations to connect to and use the DH grid, the technical connection requirements (TABs) regarding the design parameters of heating systems and substations, the usage of remotely readable heat meters, and the implementation or existence of RT-dependent tariff systems, as building owners are responsible for implementing measures on the building side (Leoni et al., 2020)
- the offer of heating services changing the relation between DH operator and customer,
- and the possibility of integrating heat sources from external parties in the DH grids.

For the *operational transition management*, the aspects studied involve

- ongoing and short-term planned action on, among others, implementing or developing heating and energy concepts to lower the temperature levels or develop low-temperature DH grids, installing remotely readable heat meters to measure the ST and RT, and lowering the temperature levels of existing DH grids.

For the *reflexive transition management*, the aspects studied comprise

- experiences made in the process of transitioning the DH grid and in regards to the involvement of actors,
- the monitoring and controlling strategies in place for the climate protection concepts and the heating concepts,
- and framework conditions necessary for the transition.

3 Methodology

The following section outlines the methods applied in the Master thesis, namely the multiple case study, the document analysis, semi-structured interviews, and the data analysis are presented.

3.1 Multiple Case Study

In the Master thesis, multiple case study is used as a research design, linking the initial questions of the study to the data to be collected and the conclusions drawn. Case studies can be used to explain, explore or describe complex, contemporary phenomena in their real-life context. According to Yin (2018), case studies are suitable when the main research questions are “what”, “how”, or “why” questions, the researcher has little or no control over behavioural events, and a contemporary phenomenon shall be studied. (Yin, 2018)
Analysing how the process of lowering the STs of existing DH grids to better integrate renewable and excess heat is managed meets these requirements. In this thesis, an exploratory approach will be adopted to explore a phenomenon about which little is known and to develop ideas for further studying (Yin, 2018).

As the evidence of multiple case studies is seen as being more compelling than that from single case studies by allowing the identification of similarities and differences of the individual cases by cross-case comparisons, a multiple case study is conducted (Yin, 2018). For answering the research question, case municipalities in Germany are selected that aim to lower the ST of their existing DH grid to better integrate renewable and excess heat sources in the future. Firstly, municipalities that seek to reduce the ST of the DH grids located in the municipality need to be identified. For this, specialised consultancies and researchers working in the field are contacted via email. Also, the State Energy Agency ThEGA is contacted via email, as DH operators in Thuringia have the legal obligation to develop a concept by 2022 on reaching a nearly climate-neutral heat supply by 2040 (Thuringia Climate Act, 2018). In addition, lists of “best practice cases” on the Euroheat & Power website and from the Climate Protection and Energy Agency of Lower Saxony are used. Furthermore, concepts from municipalities that participated in the programme “Master Plan 100% Climate Protection” funded by the BMU aiming to lower their GHG emissions by 95% compared to 1990 and their energy demand by 50% are studied (BMU, undated). Secondly, for the identified municipalities, the departments responsible for implementing the climate protection concept and the DH operator are contacted and asked for an interview. All municipalities in which someone agreed to an interview, six in total, are included in the Master thesis.
For these six case municipalities, multiple sources of evidence are examined, creating contextual and more in-depth knowledge than studying only one source of data (Bowen, 2009; Yin, 2018). The following sections will present the applied data collection methods in the Master thesis.

3.2 Document Analysis

In the Master thesis, existing documents are analysed to provide data on the context of the case studies and research how the process of lowering the ST to better integrate renewable and excess heat sources is managed for the existing DH grids located in the case municipalities (Bowen, 2009).

For this, among others, the following sources have been studied:

- Climate protection strategies, including
  - for Frankfurt am Main, the Energy and Climate Protection Concept,
  - for Frankfurt am Main, Potsdam, and Rostock, the concepts developed in the project “Master Plan 100% Climate Protection”,
  - for Henningsdorf, the Climate Protection Framework Concept developed by the Stadtwerke Henningsdorf (SWH),
  - for Jena, the Sustainability Strategy,
  - for Potsdam, the Action Programmes for the Master Plan 100% Climate Protection,
  - and for Springe, the Climate Protection Action Programme,
- strategies and studies on the future development of the DH grid, including
  - for Frankfurt am Main, the heating and cooling strategy developed within the framework of the EU-funded project “Hotmaps–Heating and Cooling Open Source Tool for Mapping and Planning of Energy Systems”,
  - for Henningsdorf, the final report for the first project phase of the project “Heating Hub”,
  - for Jena, the project reports “Integrated Energy and Heat Concept for Jena 2050” and the report developed in the project “Transformation Strategies DH”, taking Jena as a model region,
  - for Potsdam, the sub-study “Climate-neutral DH” developed within the framework of the Master Plan 100% Climate Protection,
  - and for Rostock, data obtained from the initial and interim presentation of the Heat Plan,
- websites from the DH operator, focusing on the TABs, the DH tariffs, and the offer of service agreements,
- and information on climate protection and DH available on the City Council Information Systems.

3.3 Semi-structured Interviews

For gaining further information on the research question that could not be found through the document analysis, 12 interviews are conducted in the Thesis. The interviews are completed as semi-structured interviews and are conducted in German on the online meeting platforms Zoom, Teams, Jitsi, and via phone. The semi-structured interview is chosen as a research method to address specific dimensions relevant to the research question and take up new

meanings brought up by the respondent. This flexibility gained by combining structured and unstructured elements is beneficial when the researcher is familiar enough with the topic to identify questions but cannot anticipate the interviewee's responses. (Galletta, 2013)
In this way, it is possible to compare the results of the individual case studies and explore the process of managing the transition of lowering the ST of the DH grids located in the case municipalities to better integrate renewable and excess heat sources.

As described in the chapter *Multiple Case Studies*, departments responsible for implementing the climate protection concept and the DH operator in the municipality are contacted and asked for an interview. These experts, either from the municipality or the DH operator, provide insider knowledge on how the transition is managed in their municipality (Przyborski et al., 2013). After conducting the interviews, it became apparent that it is sensible to gain data and perspective from both somebody from the climate protection department and somebody from the DH operator for each case municipality. So, either the person emailed prior or a contact person named by the respective interviewee is asked for an interview. Data on the interviews conducted can be found in Table 3. As the redevelopment manager in Springe coordinates between the municipality and the DH operator and is the contact person for the project "DH for Springe", only the redevelopment manager is interviewed for Springe (Michalczyk & Schwitalski, 2019). For Jena, the practitioner from the business customer sales department of Stadtwerke Energie Jena-Pößneck (SWEJ) is mainly asked about involving the customers in the process. The practitioner from the Stadtwerke Jena Netze (SWJN), responsible for the technical management of the DH grid (Interview 7), is mainly asked about the strategic development of the DH grid.

Table 3: Information on the interviews conducted in the Master thesis

Municipality	Interviewees Job Position	Interview Time	Interview Date	Pseudonym
Frankfurt am Main	Climate Protection and Energy Department of the City called Energiereferat	73 Minutes	May 7	Interview 1
	DH Department of Mainova	49 Minutes	June 18	Interview 2
Henningsdorf	Technical Department of SWH	73 Minutes	April 30	Interview 3
	Climate Competence Centre, located at Cobios Consult	63 Minutes	June 11	Interview 4
Jena	Business Customer Sales Department of SWEJ	47 Minutes	May 12	Interview 5
	Climate Protection Department of the City	29 Minutes	June 10	Interview 6
	Strategic Department of SWJN	54 Minutes	June 15	Interview 7
Potsdam	Strategic and DH Department of Energie und Wasser Potsdam (EWP)	70 Minutes	May 7	Interview 8
	Climate Protection Department of the City	61 Minutes	June 11	Interview 9
Rostock	Climate Protection Department of the City	63 Minutes	May 21	Interview 10
	Strategic and DH Department of Stadtwerke Rostock (SWR)	69 Minutes	June 15	Interview 11
Springe	Redevelopment Manager, employed by the Stadtwerke Springe (SWS)	61 Minutes	May 4	Interview 12

For ensuring that the aspects of interest are covered, an interview guide is developed beforehand for each interview. The interview guides address the four activities of transition governance and integrate the data that has already been collected beforehand. In the interview, follow-up questions and prompts are used to draw the interviewee deeper into the topic and gain more in-depth knowledge. (Galletta, 2013)

A rough timeline was developed for the questions beforehand to keep an eye on the timeframe during the interview. The interview guides used for the semi-structured interviews are included in Appendix A.

The interviews were recorded and transcribed to enhance concentration on the interviewee and to enable thorough data analysis. However, due to technical issues, it was not possible to record the interview with the interviewees from EWP. Instead, notes were taken, and the interviewees showed a presentation created for informing the housing associations on the topic. During and after the presentation, questions from the interview guide were asked. Simultaneously listening and writing has impaired the concentration and the data collected from the interview. For aspects that are not entirely clear from the written notes, the interviewee is asked back if the statement is correct. For ensuring that all other interviews could be recorded despite any possible technical problems, an audio recording application is installed on the mobile phone and used as a backup recording.

The data collection process in the Master thesis can be seen as an iterative process (Yin, 2018). The data obtained from the document analysis and the lack thereof are used to form the questions asked in the semi-structured interviews. Semi-structured interviews enable to bring new aspects that have not been thought of before (Galletta, 2013). At the end of the interview, the interviewee is asked if it is possible to ask further questions via email. For clarifying or gaining information on these new aspects, literature is read up and, if necessary, the interviewees are contacted again and kindly asked if they could answer the questions included in the email.

3.4 Data Analysis

The collected data in the Master thesis is analysed by taking transition management as a theoretical lens, structuring the data according to the four types of governance described in the chapter Transition Management. The aspects studied are both developed based on literature read beforehand on lowering the ST of existing DH grids and from the data collected in the Master thesis. For better coherence, the reflections directly related to the strategic, tactical, and operational activities are included in the respective sections.

For analysing the semi-structured interviews, relevant statements in the transcription are marked with four colours, using one colour for each type of governance activity. For each case municipality, the statements extracted from the respective interviews - in the case of Springe one interview - and the data obtained from the document analysis are merged for each type of governance activity. Based on this database, an individual case study for each case municipality, consisting of four chapters, one chapter for each type of governance activity, is written. To better compare the findings of the individual case studies, the structure of the individual chapters is similar. For answering the research question, the findings from the individual case studies are compared for each type of governance activity in the cross-case analysis to determine similarities and differences in how the process of lowering the ST of the existing DH grids to better integrate renewable and excess heat sources is managed (Yin, 2018).

4 Case Description

The following section presents the six case municipalities studied in the Master thesis. The municipalities differ regarding their size, the federal states they are located in, and the parameters of their DH grid(s). Common for all case municipalities is that they aim to lower the ST of the existing DH grids located in the case municipalities to better integrate renewable and excess heat sources.

Table 4 shows the general facts of the case municipalities. Only for Potsdam, a statistic on the flat owners could be found. For the other case municipalities, data from the (mainly) municipal-owned housing association, for Springe, the housing association named by the practitioner, and for Henningsdorf, additionally the largest housing associations is included in the table (B.A.U.M. Consult, 2015; Interview 12).

Table 4: General characteristics of the case municipalities

Case Municipality	Number of Inhabitants	State	Flat Owners
Frankfurt am Main	Around 759,000 (City of Frankfurt am Main, 2021a)	Hesse	Municipal-owned: 13% (AGB Frankfurt Holding, undated; City of Frankfurt am Main, 2021a)
Henningsdorf	Around 26,800 (City of Henningsdorf, 2020)	Brandenburg	Municipal-owned: 25% (Flecken et al. 2015; HWB, 2019; SWH, undated a) Largest housing association: 40% (Flecken et al. 2015; SWH, undated a; WGH, 2020)
Jena	Around 108,000 (City of Jena, 2021)	Thuringia	Mainly municipal-owned: 24% (City of Jena, 2021; jenawohnen, 2021)
Potsdam	Around 182,000 (City of Potsdam, 2021a)	Brandenburg	Municipal-owned: 20% (City of Potsdam, 2021b) Housing associations: 18% (City of Potsdam, 2021b)
Rostock	Around 209,000 (City of Rostock, 2021a)	Mecklenburg-Western Pomerania	Municipal-owned: 29% (City of Rostock, 2021b; WIRO, undated)
Springe	Around 30,000 (City of Springe, 2021)	Lower Saxony	Housing association: 4% (KSG Hannover, 2021; Region Hannover, 2020)

Table 5 displays the characteristics of the DH grids located in the case municipalities. Data on the number of customers or installed substations, the thermal capacity of the heat supply sources, the amount of heat supplied by the DH grid, and the number of municipal buildings, industrial and commercial buildings supplied by DH grid is not available for all DH grids located in the case municipalities. Therefore, it was decided to exclude them from the table. These figures would allow comparing the size of the DH grids better. As these figures are not available for every DH grid, to give an indication, the total number of households supplied by DH is, if not available, is calculated. For Frankfurt am Main, Jena, and Springe, the requirements of the RT written in the TABs are presented. Studies show that the substations and heating systems are often not working correctly, and the RTs are therefore, assumed to be higher than the ones written in the TABs (Averfalk et al., 2017; Gadd & Werner, 2015).

Table 5: Characteristics of the DH grids located in the case municipalities

Case Municipality	Size of the DH grid(s)	Temperatures of the DH grid(s)	Share of DH supplied by renewables	DH Operator
Frankfurt am Main	268 km long, excluding the DH grid using steam as a heat carrier (Mainova, 2021a) Supplies around 12-15 % of the households (Interview 1) => around 48,000-60,000 (City of Frankfurt am Main, 2021b; Interview 1)	ST: main DH grid 80 to up to 130 °C, smaller DH grids up to 90°C (Fraunhofer IBP, 2015) RT: 50°C (Mainova, undated a)	Around 21.6 % in 2019 (Magistrate of Frankfurt am Main, 2021a)	Mainova AG[5] operates the DH, electricity, and gas grid, as well as the water supply system (Mainova, 2021a) 80% of Mainova is owned by the municipality (Prohaska et al., 2020)
Hennings-dorf	58 km long (SWH, undated a) Supplies around 80% of the households (Flecken et al. 2015) => around 9,800 households (SWH, undated a)	ST: 85 to up to 108 °C (Henningsdorf City Council, 2017) RT: 60 °C (Henningsdorf City Council, 2017)	Around 54 % in 2015 (Henningsdorf City Council, 2017)	Stadtwerke Henningsdorf GmbH[6] operates the DH grid and owns 50% of the gas and the electricity grid (SWH, undated a) 100% of SWH are owned by the municipality (SWH, undated a)
Jena	226 km long, including the DH grid using steam as heat carrier (SWEJ, undated b) Supplies around 60% of the households (Interview 7) => around 36,000 households (Interview 7; City of Jena, 2021)	ST: primary DH grid 90 to 130 °C, secondary DH grid Jena-Nord 70 to 110 °C (Schöttke et al., 2016) RT: 55 °C (SWJ, 2019)	Around 2.7 % currently (Interview 5)	Stadtwerke Energie Jena-Pößneck GmbH operates the DH, electricity, and gas grid and owns over 90% of the housing association jenawohnen (Schöttke et al., 2016; SWEJ, undated b) 72.1% of SWEJ are owned by the 100% municipal owned Stadtwerke Jena (SWJ) (Schöttke et al., 2016; SWJ, 2021)

[5] AG is a legal form of organisation, standing for stock company
[6] GmbH is a legal form of organisation, standing for company with limited liability

Table 5 (continued): Characteristics of the DH grids located in the case municipalities

Case Municipality	Size of DH grid	Temperatures of the DH grid(s)	Share of DH supplied by renewables	DH Operator
Potsdam	189 km long, 70% primary and 30% secondary DH grid (Interview 8) Supplies around 60% of the households (City of Potsdam, 2017) => around 55,000 households (City of Potsdam 2017 & 2021b)	ST: primary DH grid 95 to 125 °C, secondary DH grids 80 to 90 °C (Interview 8) RT: 63 °C in average (Interview 8)	0% in 2014 (Lange et al., 2017b)	Energie und Wasser Potsdam GmbH operates the DH, electricity, and gas grid, as well as the water supply and sewage system (City of Potsdam, undated a) 65% of EWP are owned by the 100% municipal owned Stadtwerke Potsdam (SWP), SWP also operates a.o. the waste system through Stadtentsorgung Potsdam, and the public transport through ViP Verkehrsbetriebe Potsdam (City of Potsdam, undated a & b)
Rostock	406 km long, 67% primary and 33% secondary DH grid (SWR, 2020a) Supplies around two-Thirds of the households (SWR, 2020a) => around 82,000 households (City of Rostock, 2021b; SWR, 2020a)	ST: primary DH grid 85 to 130 °C, secondary DH grids up to 100°C (Interview 11) RT: 50°C in average (Interview 10)	0 % in 2020 (Schubert, 2020) 100% fossil fuels with CO2 compensation (Schubert, 2020)	Stadtwerke Rostock AG operates the DH, electricity, gas, and broadband grid (SWR, undated) 75% of SWR are owned by the municipality (Interview 10)
Springe	The length of the total DH grid is not available (Interview 12) Planned to supply the heat demand of around 16% of the households (Region Hannover, 2020; SWS, undated a) => around 2,400 households (SWS, undated a)	ST: up to 95 °C (Interview 12) RT: 50 °C for SH and 60°C for DHW systems (SWS, 2017)	Planned to be supplied by around 77 % (Felsmann & Sander, 2018)	Stadtwerke Springe GmbH operates the DH, electricity, and gas grid (SWS, undated b) 50.5 % of SWS are owned by the municipality and 16.5% owned by BS Energy, Stadtwerke Hameln, and Veolia each (SWS, undated b)

5 Results

The following section presents the results of the cross-case analysis, answering the research question: *How is the process of lowering the supply temperature of the existing DH grids located in the six case municipalities managed?* The results of the individual case studies can be found in Appendix B to G. The chapter is divided into four main sections, one for each governance level of transition management. After each section, a partial conclusion summarises the findings.

5.1 Strategic Transition Management

In the following sections, the goals set by the case municipalities, the transition arenas, the investigations regarding the current and future heat demand, the energy efficiency of buildings and locally available heat sources, and the target future temperature levels of the DH grids are presented.

5.1.1 (Politically) Set Goals

Especially as climate protection is not a mandatory task of municipalities, binding political goals are a crucial prerequisite for implementing the targets, highlighting the willingness to act and creating the necessary binding force (Link et al., 2018).

Frankfurt am Main, Jena, Potsdam, and Rostock have adopted targets for climate protection. Frankfurt am Main and Potsdam have set long-term goals to reduce GHG emissions by 95% by 2050 compared to 1990 levels and to use 100% renewable energies by 2050 (City of Potsdam et al., 2013; Magistrate of Frankfurt am Main, 2021a). Additionally, Frankfurt am Main has also adopted the goal to halve the energy demand by 2050 compared to 2010 (Magistrate of Frankfurt am Main, 2021a). Jena and Rostock have adopted, according to the transition management theory, medium-term goals for climate protection, reducing the GHG emissions by 84 to 91 % by 2030 compared to 1990 levels and becoming climate-neutral by 2035 (City of Jena, 2020; Loorbach, 2007; Rostock City Council, 2020a; ThINK, 2019).

In Henningsdorf, the City Council decided that necessary replacement investments should be made in CO2-neutral heat generation facilities (SWH, 2018).

5.1.2 Transition Arena

A transition arena provides space for frontrunners to develop a comprehensive viewpoint on a given problem at the system level and formulate shared visions of a fundamentally different future (Loorbach, 2007).

In the case municipalities, concepts for climate protection were developed. For Frankfurt am Main, Potsdam, Rostock, and Springe, climate protection concepts for the time horizon 2050, and for Henningsdorf and Jena, concepts for a time horizon of 2030 were developed (B.A.U.M.

Consult, 2015; BMU, undated; City of Jena, 2020; City of Springe, 2010). For Frankfurt am Main and Potsdam, the Master Plan 100% Climate Protection was created to analyse how a 95 % reduction of GHG emission and a 50 or 35 % reduction of the energy demand, respectively, can be reached (Fraunhofer IBP, 2015; Lange et al., 2017a). To better integrate the citizens, the Energy and Climate Protection Concept, the basis for action on climate protection in Frankfurt am Main, will be updated with extensive citizen participation (Interview 1; Magistrate of Frankfurt am Main, 2021a). For Rostock, however, the Master Plan 100% Climate Protection does not include any analyses for the future development of the existing DH grid were undertaken (Interview 10). For Springe, the climate protection concept, stating the aim to reach 2 t GHG emissions per inhabitant by 2050, recommends that the potential for developing small DH grids shall be further analysed (City of Springe, 2010). For Henningsdorf, the climate protection concept states the potential of reducing GHG emissions by 10% by 2030 compared to current levels and recommends developing a heating concept for 2050 (B.A.U.M. Consult, 2015). For Jena, the sustainability strategy developed with representatives from the municipal administration and politics, civil society, and local businesses states the aim of reducing the GHG emissions by 84 to 91% by 2030 compared to 1990 levels and lists the development of a concept showing how the energy demand can be covered by at least 80%, preferably 100% renewable sources by 2040 (City of Jena, 2020; ThINK, 2019).

In the case municipalities, concepts for SH and DHW preparation and the DH grid were or are currently being developed within the framework of funded projects or to comply with the legal obligations. Heating concepts were created for Frankfurt am Main, Henningsdorf, Potsdam and Jena, taking 2050 as the time horizon (Cobios Consult, undated; Lange et al., 2017b; Paar et al., 2013; Prohaska et al., 2020; Schöttke et al., 2016). They analyse the decarbonisation of the SH and DHW preparation, the decarbonisation of the DH grid, or how to significantly increase the share of renewables in the DH grid (Cobios Consult, undated; Lange et al., 2017b; Paar et al., 2013; Prohaska et al., 2020). Frankfurt am Main and Potsdam aim to use 100% renewable and excess heat sources by 2050 and Henningsdorf to make necessary replacement investments in CO2-neutral heat generation facilities for the DH grid (City of Potsdam et al., 2013; Magistrate of Frankfurt am Main, 2021a; SWH, 2018). For Jena, as required by the Thuringia Climate Act, a concept for a nearly climate-neutral DH supply by 2040 is currently being developed (Interview 5 & 7). For Rostock, a concept on a fossil-free heat supply is currently, and for Springe, a concept for supplying the DH grid with locally available renewable and excess heat sources was developed (Interview 10 & 12). The heating concepts were or are currently created mainly by the DH operator or the climate protection department together with or without external experts (Paar et al., 2013; Prohaska et al., 2020; Lange et al., 2017b; Schöttke et al., 2016; Interview 5, 7 & 12). For the development of the Heat Plan for Rostock, working groups consisting of representatives from SWR, the municipality, state association of the housing companies, local and external experts were developed (Interview 10; Zander & Hempfling, 2020). For Frankfurt am Main, Potsdam, Rostock, and Springe, the concepts consider both the future heat demand and the renewable and excess heat sources available to cover the demand together (Interview 10 & 12; Lange et al., 2017a; Prohaska et al., 2020).

The district level provides a middle ground between the individual building and the entire city (Riechel, 2016). In Frankfurt am Main, Potsdam, Rostock, and Springe, the district level is identified as an essential planning level. In Frankfurt am Main and Rostock, energy-efficient urban redevelopment concepts are to be developed (Magistrate of Frankfurt am Main, 2021a; Rostock City Council, 2020b). The climate protection sub-concept "Renewable Energy" analyses how the energy demand of three existing and nine construction areas in Frankfurt am Main can be covered as much as possible with local renewable and excess heat sources (Kobelt & Rochard, 2019). In Frankfurt am Main, the existing commercial area in Fenchenheim-Nord/Seckbach shall be converted into a model for sustainable commercial spaces (Magistrate of Frankfurt am Main, 2021c). In Potsdam, energy and climate protection concepts for the districts Krampnitz, Drewitz, and Schlaatz were or are currently developed (Interview 9). In Drewitz, an integrated energy and climate protection concept was developed for reducing GHG emissions by over 80% by 2050 (City of Potsdam et al., 2013). In Krampnitz, a former barracks complex will be converted into a new residential district, and a fossil-free energy supply by 2040/50 is to be developed, including a new DH grid with a ST of 50°C and RT of 30°C using renewable heat sources (City of Potsdam, 2021c; EWP, 2018; Potsdam City Council, 2020a). For the district Schlaatz, concepts are currently being developed, including how to lower the temperature of the DH grid and involving the local citizens by developing future, sustainable visions (Interview 9). In Rostock, a transition plan for a district to lower the temperatures of the DH grid is to be developed (Interview 11). As stated above, the three energy-efficient urban redevelopment concepts for Springe analyse how the DH grid could be supplied by locally available renewable and excess heat sources (Interview 12).

The concepts for a sustainable commercial area in Frankfurt am Main and for the districts Krampnitz, Drewitz, and Schlaatz, also focus on other aspects, like mobility and green spaces (City of Potsdam, 2013 & 2021c; Magistrate of Frankfurt am Main, 2021c; Schwarz, 2019). By integrating other aspects than energy-efficient refurbishment of buildings and energy or heat supply, synergies can be generated and exploited (Interview 10). Furthermore, experiences from the district Drewitz show that local citizens seem to be not that interested in energy topics (Interview 9). Including other aspects in the district concepts, enables to address the local citizens better (Interview 9). In Schlaatz, together with local citizens visions for a sustainable Schlaatz in 2030 are created (Schwarz, 2019). The practitioner from the climate protection department in Rostock states that the focus of the energy-efficient urban redevelopment will depend on the structure of the districts (Interview 10). For districts with many historic facades or old, not modernised buildings, the focus will be more on energy-efficient refurbishment; for other districts, the focus will also include other funded aspects, like the development of a broadband grid or renewing the water supply (Interview 10). For Springe, ideas including other aspects, like mobility and community, were developed, but the focus of the three energy-efficient urban redevelopment concepts is on the energy-efficient refurbishment of buildings, the DH grid, and photovoltaic (Interview 12).

5.1.3 Heat Demand and Available Heat Sources

As stated in the *Problem Area*, lowering the temperatures of existing DH grids and switching the supply to renewable and excess heat sources requires taking both the supply and demand side into account (Krog et al., 2020).

The case municipalities have conducted spatial analyses for the heat demand. For Frankfurt am Main, the current heating demand was assessed using energy indicators for Germany adjusted to Frankfurt by heating degree days for the whole city (Prohaska et al., 2020). For Rostock, data on DH and gas consumption from SWR were analysed on the district level (Interview 10). For Henningsdorf, the current heat density per street has been assessed using DH consumption data from SWH on street level and energy indicators based on construction periods (B.A.U.M. Consult, 2015). For Potsdam, a city model combining existing (spatial) data sets on building location, storeys, historic preservation, DH and gas consumption on street level, and the number of central firing places was developed to make statements on the heat demand at the district and city level (Lange et al., 2017a).

For Jena and Springe, the heat demand and energy-efficiency of buildings were analysed for districts with similar building stock and the areas covered by the energy-efficient urban redevelopment concepts, respectively (Interview 12; Schöttke et al., 2016). For Jena, reference buildings were developed for which energy indicators and heat demand were simulated (Schöttke et al., 2016). For Springe, gas consumption data from SWS, data obtained from the energy consultancy offered by the redevelopment manager, data from site visits, and energy indicators recorded for Hannover were used (Interview 12). For Rostock, data on the energy efficiency of buildings owned by housing associations are analysed on the district level (Interview 10).

For assessing the potential of renewable and excess heat sources, investigations are or were conducted in the case municipalities. The geothermal potential has been assessed for Frankfurt am Main, Henningsdorf, Jena, Potsdam, and Rostock (Prohaska et al., 2020; Zander & Hempfling, 2020; Interview 3 & 6; Lange et al., 2017a). In Frankfurt am Main, Potsdam, Rostock, and Springe the potential of solar thermal, excess heat and biomass has been assessed (Prohaska et al., 2020; Zander & Hempfling, 2020; Interview 12; Lange et al., 2017a). For Frankfurt am Main, an excess heat register maps the potential and temperature levels of excess heat from data centres, industry, wastewater, wastewater treatment plant, and river water for the whole city (Prohaska et al., 2020; Magistrate of Frankfurt am Main, 2021b). For Potsdam and Rostock, an energy utilisation plan and a heat map are to be developed, spatially mapping the energy and heat demand, respectively, the supply infrastructure, and the available renewable energy and excess heat sources to cover the demand (Interview 9 & 10). For Jena, the potential for using solar thermal and excess heat is analysed, focusing on specific sites and not available for the whole city (Interview 7). Opposed to the other case municipalities, Henningsdorf focuses on the techno-economic potential of the heat sources (B.A.U.M. Consult, 2015; Interview 3). In specific projects, the current techno-economic potential for solar thermal, excess heat from the local steel plant, and an electrode boiler converting excess electricity into heat is analysed (Interview 3). For integrating decentral, fluctuating renewable, and excess heat sources into the DH grid simulations were carried out to identify possible bottlenecks and optimisation measures and design the size of the heat storage (SWH & Ruppin Consult, 2017).

For the future heat demand, Frankfurt am Main, Rostock, and Springe analysed the heat demand with consideration of the available renewable and excess heat sources to cover the heat demand. For Frankfurt am Main, a reduced regional biomass potential is used because biomass is to be prioritised for industrial applications requiring higher temperatures (Prohaska et al., 2020). For Rostock, the local and regional potential, and for Springe, the potential of wood from the surrounding forests is used in the analyses (Interview, 12; Zander & Hempfling, 2020). For Frankfurt am Main and Rostock, the heat demand and the assessed potential of renewable and excess heat sources were simulated hourly with simulation models for the whole city (Interview 10; Prohaska et al., 2020). For Frankfurt am Main, the energy demand and the local renewable energy and excess heat sources available to cover this demand were also modelled on district level for nine construction and three existing districts (Kobelt & Rochard, 2019). The results show that reducing the heat demand is crucial to meet as much of the heat demand, especially of the peak demand, with renewable and excess heat sources (Interview 10; Magistrate of Frankfurt am Main, 2021b; Prohaska et al., 2020). For Springe, analyses for a DH grid supplied by locally available renewable and excess heat sources show that the heat demand needs to be reduced as much as possible using the EnerPhit standard to cover the heat demand of the connected buildings (Interview 12).

For Frankfurt am Main and Potsdam, the renovation rate and depth were analysed with focus on the technical potential for reaching a 50 and 35% energy demand reduction, respectively (Fraunhofer IBP, 2015; Lange et al., 2017a). For Jena, the future heat demand in the energy supply concept has been simulated for three renovation rates: The first is seen as most realistic, the second with the current renovation rate, and the third with a significantly higher rate to approximately reaching a climate-neutral building stock by 2050 (Schöttke et al., 2016). For

Henningsdorf, scenarios for the future heat demand are developed for 2050, indicating that making the DH supply climate-neutral is faster than waiting for the energy-efficient refurbishment of the buildings expected after 2025 (Interview 4).

In Frankfurt am Main, the Master Plan 100% Climate Protection cites various social, financial, and technical barriers for increasing the renovation rate. For Potsdam, technical restrictions and the social acceptancy are listed as key obstacles, and for Springe, the lack of financial resources, the complexity of the topic and the oversupply of information unsettling the building owners (City of Springe, 2010; Fraunhofer IBP, 2015; Lange et al., 2017a).

5.1.4 Future Temperature Levels of the DH Grid

The future target temperature levels of the DH grid depend on the locally available renewable and excess heat source, the existing DH grid, and the buildings connected to the DH grid (IRENA & AAU, 2021).

The case municipalities lack necessary data on the temperature demand of the heating systems installed in the buildings (Interview 2, 3 7, 11 & 12).

Frankfurt am Main, Henningsdorf, Rostock, and Springe have currently no determined goals for the temperature levels of the DH grids in the long-term future (Interview 2, 3, 11 & 12). For Frankfurt am Main, Rostock, and Springe, concepts will be developed for lowering the temperatures, determining the targets for the future temperature levels of the DH grids (Interview 2, 11 & 12). For Henningsdorf, the practitioner from SWH states that the future temperature levels will be analysed sometime in the future (Interview 3).

In Potsdam and Jena, future temperature levels were identified based on simulations and for Jena also on tests (Interview 5, 7 & 8). The future temperature levels of the DH grids in Potsdam are 30°C for the RT, 80°C for the ST in the primary, and 50°C for the ST in the secondary DH grids (SWP, 2020). In Jena, the future temperature levels of the DH grids are 40°C for the RT, and 60-90°C, 70-90°C, 75-90°C, and 80-115°C for the STs of the DH grids (SWJ, 2019).

5.1.5 Partial Conclusion

Binding political goals are a crucial prerequisite for the implementation of climate protection goals. Except for Springe, all case municipalities have adopted political goals on climate protection or in the case of Henningsdorf, for using climate-neutral heat sources in the DH grid. Besides long-term climate protection goals, Frankfurt am Main and Potsdam have also set the target to use 100% renewable energy by 2050. Jena and Rostock have adopted, according to the transition management theory, middle-term goals.

All case municipalities have developed climate protection concepts for the time horizon 2030 or 2050 and various targets. The climate protection concepts developed for the time horizon

2030 state that further analyses on the energy supply by 2040 and heat supply by 2050 shall be developed.

Through funded projects or to comply with the legal requirements, all case municipalities developed or are developing heating concepts. For Frankfurt am Main, Henningsdorf, and Rostock, heating concepts for decarbonising the SH and DHW preparation and for Jena, Potsdam, and Springe, on decarbonising the DH grid were or are developed. Frankfurt am Main and Potsdam aim to use 100% renewable and excess heat sources by 2050, and for Rostock, a concept for a fossil-free heat supply is currently being developed. Henningsdorf decided to make necessary replacement investments in CO2-neutral heat generation facilities for the DH grid. For Jena, a concept for reaching a nearly-climate neutral DH supply by 2040 is currently, and for Springe, supplying the DH grid with locally available renewable and excess heat sources was developed. Except for the Heat Plan in Rostock, the heating concepts on the city level were or are currently developed mainly by the DH operator or the climate protection together with or without external experts. The Heat Plan also includes representatives from different municipal departments, the state association of the housing companies, and local experts.

The district level is emphasised as an essential planning level in Frankfurt am Main, Potsdam, Rostock, and Springe. On the district level, the targets set for the whole city can be concretised, models and technical solutions developed, and local actors integrated into developing the concept. Integrating other aspects, like mobility, green spaces, and renewing the water supply, in the district concepts can generate synergies and enable to address the local citizens better.

For the transition, both the supply and demand side need to be taken into account. For the heat demand, Frankfurt am Main, Henningsdorf, Potsdam, and Rostock have conducted spatial analyses to make statements on the street, district, or city level. In addition to the heat demand, the energy efficiency of buildings was analysed in Jena for districts with similar building stock, in Springe for the areas covered by the energy-efficient urban redevelopment concepts, and in Rostock for the buildings owned by housing associations.

For the available potential of renewable and excess heat sources, the case municipalities have conducted investigations. For Potsdam and Rostock, maps showing the spatial energy and heat demand, respectively, the supply infrastructure, and the available renewable and excess heat sources are to be developed. For Frankfurt am Main, an excess heat register, mapping the potential and temperature levels of excess heat source, was developed. For Jena, the potential of solar thermal and excess heat is analysed, focusing on specific sites. For Henningsdorf, on the other hand, the analyses focus on the techno-economic potential of the heat sources.

For Frankfurt am Main, Rostock, and Springe, the future heat demand was analysed together with the renewable and excess heat sources available to cover the demand, using simulations for Frankfurt am Main and Rostock. For biomass, the local or regional potential is used and for Frankfurt am Main, the regional potential is reduced as biomass is to be prioritized for other sectors. The investigations show that the heat demand needs to be significantly lower to cover as much of the heat demand with the local or regional available heat sources. For Frankfurt am Main and Potsdam, the renovation rate for reaching 50% or 35% energy demand reduction, respectively, were analysed. For Jena, the future heat demand has been simulated for three renovation rates, including one to approximately reach a climate-neutral building stock by 2050. For Henningsdorf, scenarios for the future heat demand are developed for 2050. For Frankfurt am Main, Potsdam, and Springe, the climate protection concepts list key obstacles for increasing the renovation rate.

The case municipalities lack the necessary data on the temperature demand of the heating systems installed in the buildings. In Potsdam and Jena, the future ST and RT levels of the DH grids have been determined using simulations and tests. The future temperature levels for Potsdam are 30°C for the RT, 80°C for the ST in the primary, and 50°C for the ST in the secondary DH grids. For Jena, the future temperature levels of the DH grids are 40°C for the RT, and 60-90°C, 70-90°C, 75-90°C, and 80-115°C for the STs of the DH grids.

For Frankfurt am Main, Rostock, and Springe, concepts will be developed for lowering the temperature, determining the targets for the future temperature levels of the DH grids. In Henningsdorf, the future temperature levels will be analysed sometime in the future.

5.2 Tactical Transition Management

The following section will present the strategies of the case municipalities for the transition, the created organisational structures for the implementation, imposed legal obligations to connect to and use the DH grid, the connection requirements specified in the TABs, measures to identify and remove faults, and the integration of external heat sources.

5.2.1 Strategies for the Transition

Potsdam, Springe, and Jena, have started to outline how the temperature of the DH grid shall be reduced to better integrate renewable and excess heat sources in the future. For Potsdam, the sub-study "Climate-neutral DH" outlines the pathway for transforming the DH grid, lowering first the RTs and then the STs, first in individual parts of the DH grid and then in the entire DH grid by lowering the temperature levels written in the TABs and developing incentive systems (Interview 8; Lange et al., 2017b). For Springe, the strategy is to first connect as many buildings as possible to the DH grid and then gradually decrease the temperature of the DH grid, using existing funding programmes to prepare the buildings for lower ST (Interview 12). For reducing the RT, a strategy is to be developed for Springe (Interview 12). For Jena, the strategy is to reduce the requirements of the RT written in the TABs and develop RT-dependent tariff structures (Interview 5 & 7; SWJ, 2019). For Jena, the concept currently being developed will list measures on how to reach a nearly climate-neutral DH supply by 2040 (Thuringia

Climate Act, 2018). However, the concept will not include the building side owing to a lack of data and the fact that statements can only be made about buildings owned by SWEJ (Interview 5 & 7). For Rostock, a milestone plan is currently being developed, analysing how a fossil-free heat supply can be reached (Interview 10). For Frankfurt am Main and Rostock, strategies are to be developed for decarbonising the DH grid, including lowering the temperatures of the existing DH grids (Interview 2 & 11). For Henningsdorf, the sub-concept “CO2-free Heat Supply 4.0” shows that lowering the temperatures of the DH grid is a process that should be continuously undertaken (Interview 4). Asked about future goals to lower the temperatures in the long term, the practitioner from SWH states that the topic will be considered sometime in the future (Interview 3).

As stated above, in Frankfurt am Main, Potsdam, Rostock, and Springe, the district level is identified as an essential planning level. For Frankfurt am Main and Potsdam, the districts for the energy and energy-efficient redevelopment concepts are selected as existing urban development processes are ongoing in these districts, enabling the use of established district management structures (Interview 1 & 9). In Potsdam, the energy utilisation plan is to be used to identify districts for future energy concepts (Interview 9). For Rostock, the districts for the energy-efficient redevelopment concepts are selected based on the heat demand density and the willingness of the housing associations (Interview 10). The pilot district, in which the temperature is to be lowered first is identified based on hydraulic conditions (Zander, 2021). For Springe, the districts are selected to largely cover the area in which the DH grid is to be constructed (Michalczyk & Schwitalski, 2019).
The city of Jena and SWJ have currently no plans to conduct heat analyses and heat concepts on the district level (Interview 6 & 7).

5.2.2 Creation of Organisational Structures

In the last three decades, heat supply was primarily seen as an issue to be solved by the building owners (Thamling et al., 2020). Without strategic, planned, and coordinated action, lowering existing DH grids' temperature is structurally impossible (Thamling et al., 2020). A central actor establishing communication with and between the various stakeholders, mediating and coordinating between them is essential (dena, 2019). Municipalities can create favourable implementation conditions and coordinate between the various actors involved (dena, 2019; Riechel & Koritowski, 2016).
In Frankfurt am Main, Potsdam, and Rostock, the climate protection departments are, and in Springe, the redevelopment manager is actively involved in coordinating and facilitating the process (Interview 1, 9, 10 & 11). In Henningsdorf, the Climate Competence Centre is not involved in the process anymore, the sustainability manager will do the necessary coordination between the city and SWH on climate protection in the future (Interview 3 & 4). In Jena, at the

beginning of developing the concept of a nearly climate-neutral DH supply by 2040, a meeting was held with the climate protection department and the citizen energy cooperative to exchange ideas on what to include in the concept (Interview 6). However, the practitioners from SWJ state that the development of the concept is strategically a topic of SWJ (Interview 5 & 7).

The German-stated owned investment and development bank Credit Institute for Reconstruction (KfW) funds redevelopment managers to activate and coordinate implementing the energy-efficient urban redevelopment concepts (Riechel et al., 2017).
For the energy-efficient urban redevelopment concepts in Frankfurt am Main and Rostock, redevelopment managers are to be employed to approach and involve the local actors in the process (Interview 1 & 10). In Springe, the redevelopment manager was already employed during the creation of the concept to have more continuity for coordinating between the actors, to offer energy consulting services, and to use the obtained data to develop the concept (Interview 12; Michalczyk & Schwitalski, 2019). In Potsdam, the existing working group "Arbeitskreis StadtSpuren" is involved, redevelopment manager(s) are employed, and new organisational structures between SWP, the municipality, and the housing associations created to develop the districts together (Bündnis am Schlaatz, 2019; Interview 9; Potsdam City Council, 2018b). As the experiences in Drewitz with the collaborative cooperation are positive, aims to increase the collaboration are undertaken, by, for example, creating an alliance of the municipality and the housing associations for the district Schlaatz (Bündnis am Schlaatz, 2019; Interview 9; Potsdam City Council, 2018b).
For developing a sustainable commercial area in Fenchenheim-Nord/Seckbach in Frankfurt am Main, an office consisting of a climate protection manager and a site manager was established to coordinate and facilitate the process (BBSR, 2019; Magistrate of Frankfurt am Main, 2021c). After the funding period of five years, an initiative consisting of local companies and the climate protection manager will continue to coordinate the process (BBSR, 2019; Magistrate of Frankfurt am Main, 2021c).

The commitment of the municipality, the energy, and the housing industry is crucial for the successful implementation of concepts and measures (Riechel & Koritowski, 2016). In Rostock and Springe, the Heat Plan and the three energy-efficient urban redevelopment concepts, respectively, will be presented to the City Council with the aim of having a political resolution to implement them (City of Rostock, undated; Interview 12). In Potsdam and Rostock, areas for energy and heating facilities are to be secured using existing urban planning instruments (Potsdam City Council, 2020b; Zander & Hempfling, 2020). In Frankfurt am Main, Potsdam, and Rostock, the municipality and municipal housing associations take pioneering roles. The city of Frankfurt am Main and the municipal housing association in Frankfurt am Main and Potsdam decided to construct new buildings with better energy-efficient standards than the legal requirements (ifeu, 2008; Prohaska et al., 2020; ProPotsdam, undated). Furthermore, in Frankfurt am Main, leaseholders and purchasers of municipal land are obligated to construct new buildings as passive houses and for real estate investors, a subsidy programme to build passive houses and 30% of the new buildings for social housing (Magistrate of Frankfurt am Main, 2021b; Prohaska et al., 2020). In Rostock, the City Council decided that the city administration and municipal companies should reduce the GHG emissions by 95% compared to 2019 levels by 2030 (Rostock City Council, 2020a).

Initial energy consultancy informs building owners on the energy-efficient refurbishment of buildings (Freudenberg et al., 2019).
In all case municipalities, the Stadtwerke offer energy consulting services (Interview 6, 9 & 10; Mainova, undated b; SWH, undated b; SWS, undated d). In Frankfurt am Main, Jena, Potsdam, and Rostock, the Consumer Centre also offers energy consulting services (Consumer Centre Hesse, undated; Interview 6, 9 & 10).
In Frankfurt am Main, the non-profit association Energiepunkt was founded in 2010 to provide independent, free energy counselling to increase the rate and depth of energy-efficient refurbishment of buildings. For the implementation, the Energiepunkt provides lists of craftsmen companies with proven experience and quality in constructing passive houses. (Magistrate of Frankfurt am Main, 2021a & 2021b)

5.2.3 Legal Obligation to Use the DH Grid

Legal obligations offer the DH operator planning and investment security for the development and operation of investment-intensive and long-lasting infrastructure (Thamling et al., 2020). In Henningsdorf, Jena, Potsdam, and Rostock, legal obligations to connect to and use the DH grid exist (City of Henningsdorf, 2007; City of Jena, 2019; City of Rostock, 2021c; Lange et al., 2017b). In Springe, on the other hand, there is no legal obligation to connect and use the DH grid (Interview 12). Based on experiences working as an energy consultant, the practitioner states that DH tariffs are seen critically by many customers due to their natural monopoly position (Interview 12). From the point of customer protection, it is, thus, good that DH has to compete with other heat sources (Interview 12). The practitioner further says that the CO2 tax is helpful in this regard as it makes gas and oil foreseeable more expensive in the future (Interview 12). For two construction areas in Frankfurt am Main, as energy concepts show that DH has similar or even lower levelized costs of heating for the end customers than other heating systems, legal obligations were imposed to ensure planning and investment security for Mainova. For protecting the customers, a contract with Mainova was signed to make reliable statements about the price developments in the areas and to exclude arbitrariness due to the natural monopoly of the DH grid (Energiereferat, undated a). According to the practitioner from the Energiereferat, possibilities to expand the legal obligations will be analysed in future concepts (Interview 1).

5.2.4 TABs

As stated in the *Problem Area*, the RT and the ability to lower the ST depend on the installed substations' design parameters (Dalla Rosa et al., 2014). The TABs specify the technical requirements for the connection of the buildings to the DH grid. By adapting the temperature levels written in the TABs, new substations are designed to fulfil these requirements, and substations that need to be exchanged are adapted for lower temperature levels as part of the regular renewal cycle (Schöttke et al., 2016). In this way, fewer substations need to be replaced in 2050 (Interview 8).

In Jena and Potsdam, the TABs were adapted, including the future temperature levels for the STs and RTs (SWJ, 2019; SWP, 2020). In Jena, the ST are reduced by 0 to 20 °C and the RT by 15°C (SWJ, 2019). In Potsdam, the ST in the primary DH grid is to be reduced from 125 °C to 80°C and from 80 to 50°C (SWP, 2020). As written in the Problem Area, all heating systems installed in the buildings must be able to use this ST (Leoni et al., 2020). By adopting the TABs now and publishing the future, intermediate STs, the building owners are informed and can integrate adopting their buildings to lower STs in their investment decisions on building modernisation measures (Interview 8).

In Springe, the TABs prescribe to implement smart substations that can be controlled from the central control system to operate the substations and the DH grid more efficiently (Interview 12; SWS, 2017).

The TABs for the DH grids in Frankfurt am Main, Jena, Potsdam, and Rostock prescribe that flow limiters are to be implemented (Mainova, 2021b; SWJ, 2019; SWP, 2020; SWR, 2020c). Flow limiters limit the maximum volume flow that passes through the substation (Krogh Skjølstrup, 2019). The maximal volume flow is calculated based on the maximal load capacity and the agreed cooling of the RT in the contract (Mainova, 2021b; SWJ, 2019; SWP, 2020; SWR, 2020c). For Frankfurt am Main and Jena, the TABs also prescribe that the heating system in the building has to be hydraulically balanced when connecting to the DH grid (Mainova, 2021b; SWJ, 2019).

5.2.5 Identifying and Removing Faults

The basic prices of the DH tariffs in Frankfurt am Main, Jena, Potsdam, and Rostock depend on the reported maximum connection load of the substation (Interview 1 & 11; SWJ, undated; SWP, 2021). If the heating system is not functioning correctly, the thermal comfort of the customer is impaired (Krogh Skjølstrup, 2019). For ensuring thermal comfort, either the maximum flow rate needs to be increased, resulting in higher basic prices, or the heating systems optimised (Interview 10; Krogh Skjølstrup, 2019). In Frankfurt am Main, Mainova provides a guideline on the website on how to estimate if adjusting the capacity of the substation might makes sense and how to proceed then (Mainova, undated c). In Potsdam, EWP offers technical support, conducts training at guilds and housing associations regularly to ensure that heating systems are hydraulically balanced correctly (Interview 8). In Rostock, SWR points out the importance to hydraulically balance the heating systems (Interview 11).

As stated in the *Problem Area*, faults in the substations and heating systems of the customers lead to higher RTs (Averfalk et al., 2017). Data analysis and measuring the RT remotely can enable identifying customers with high RTs (Buffa et al., 2021). In Rostock and Springe, heat meters are implemented to measure the RTs of the customers remotely (Interview 2 & 12). In Frankfurt am Main and Jena, for large customers the RTs are measured remotely (Interview 2 & 5).

For faults on the customer-side that do not affect the thermal comfort, the customer has no incentive to remove them as the benefit for lower RTs lay on the side of the DH operator. For this, tariffs can be implemented to create financial incentives for the customers to act on the RTs. (Leoni et al., 2020)

In Frankfurt am Main, Jena, Potsdam, and Rostock, tariffs have or will be implemented that reward customers with lower RTs and penalise customers responsible for high RTs by paying a higher heat price (Interview 2, 5 & 8; SWR, 2021). In Frankfurt am Main and Jena, large customers who have higher RTs than agreed pay a malus, and in the case of Frankfurt am Main gain a bonus for lower RTs (Interview 2 & 5). In specific cases, Mainova might even finance the measures for lowering the RTs (Interview 2).

Physical access to the installations of customers enables to create a better relationship with the customer, test if the installations are working properly, and correct or suggest measures to correct faults. One common way to gain physical access to the installations of customers is to sign service agreements. (Månsson et al., 2019)

In Henningsdorf, Jena, and Rostock, the DH operators offer heating services to install, operate and maintain the substations of the customers, providing them access to the substation (Interview 3 & 5; SWR, undated). In Frankfurt am Main, a commissioned service provider took over to operate and maintain some of the substations of the customers (Interview 2). Being the operator of the substations and the fact that radiators are generally oversized, enable operating the heating systems in the buildings with lower temperatures than the design temperatures (Interview 3).

In Potsdam and Springe, only the local heating installers and technical services of housing associations implement, operate and maintain the substations (Interview 8 & 12). In Potsdam, EWP offers technical support, checks the schematic diagram of substations that are to be implemented, and conducts training at guilds and housing associations regularly to ensure a correct implementation (Interview 8). In Springe, the manufacturer of the substation trained the local heating installers to implement and maintain the substations correctly (Interview 12).

5.2.6 Integrating External Heat Sources

Integrating heat from external parties can limit the natural monopoly situation on the supply side (IRENA & AAU, 2021).

In Henningsdorf, decentral solar thermal heat from customers is to be feed into the DH grid, converting heat customers into so-called "heat prosumers" (SWH, 2019; SWH & Ruppin Consult, 2017).

5.2.7 Partial Conclusion

Potsdam, Springe, and Jena have started to outline how the temperatures of the DH grids are to be lowered to integrate renewable and excess heat better in the future. For Potsdam, the temperature levels are to be lowered first in individual parts of the DH grid and then in the entire DH grid by reducing the temperature levels written in the TABs and developing incentive systems. For Springe, first as many buildings as possible are to be connected to the DH grid and then gradually decreasing the temperatures using existing funding programmes to prepare the buildings for lower temperatures and developing a strategy for lowering the RTs. However, for Jena, the strategy does not take the building side into account, owing to a lack of data. For Frankfurt am Main and Rostock, decarbonisation strategies for the DH grid are to be developed, including lowering the temperatures. For Henningsdorf, there are currently no long-term strategies to lower the temperature of the DH grid.

In Frankfurt am Main, Potsdam, Rostock, and Springe, the district level provides an essential planning level for energy and heating concepts. In Springe, the selected districts largely cover the area in which the DH grid is to be constructed and in Rostock, the pilot district is identified based on hydraulic conditions. In Frankfurt am Main and Potsdam, the districts were selected as urban redevelopment processes are ongoing, using the established management structures. In Potsdam and Rostock, the districts will be selected based on the energy utilisation plan and based on the heat demand density and willingness of the housing associations, respectively. In Jena, on the part of the city and SWJ, there are currently no plans to conduct heat analyses and heat concepts on the district level.

For the heat transition, a central actor establishing communication with and between the various actors, mediating and coordinating between them is essential. In Frankfurt am Main, Potsdam, Rostock, and Springe, the climate protection departments and redevelopment manager are actively involved in the process, while in Henningsdorf and Jena, climate protection departments are not actively involved. For Henningsdorf, the sustainability manager will be involved in the future. On the district level in Frankfurt am Main, Potsdam, Rostock, and Springe, redevelopment managers were or are to be employed to coordinate between the actors. In Frankfurt am Main, for developing a sustainable commercial area, a site management office was established and an initiative was founded to coordinate the process together with the climate protection manager after the funding period. In Potsdam, a working group coordinates between the housing associations, and new organisational structures between SWP, the municipality, and the housing associations are created to develop the districts together. In Frankfurt am Main, for developing a sustainable commercial area, a site management office was established and an initiative was founded to coordinate the process together with the climate protection manager after the funding period.

For a successful implementation of concepts and measures, the commitment of the key actors is crucial. In Rostock and Springe, the developed heating concepts will be presented to the City Council with the aim of having a political resolution to implement them. In Potsdam and Rostock existing urban planning instrument will be used to secure areas for energy and heating facilities. Furthermore, in Frankfurt am Main, and Potsdam, the municipality and municipal housing associations take pioneering roles, deciding to build new buildings with a better energy efficiency than required.

Initial energy consultancy informs building owners on the energy-efficient refurbishment of buildings. In all case municipalities, the Stadtwerke offer energy consulting services, and in the larger cities also the Consumer Centres. In Frankfurt am Main, a non-profit association was founded in 2010 to provide independent, free energy counselling to increase the rate and depth of energy-efficient refurbishment of buildings.

Legal obligations to connect and use the DH grid give the DH operators necessary planning and investment security, but also make customers dependent on the prices of the natural monopoly. In all case municipalities except for Springe, legal obligations to connect to and use the DH grid exists. In Frankfurt am Main, legal obligations were imposed for two construction areas after energy concepts showed that DH has similar or lower costs than other heating technologies and after signing a contract with Mainova on the future price development.

The TABs specify the technical requirements for the connection of buildings to the DH grid. In Jena and Potsdam, the TABs were adapted, lowering the design parameters for the ST and RT. In Jena, the ST are to be reduced by 0 to 20 °C and the RT by 15°C (SWJ, 2019). New substations are designed according to these requirements, and existing ones are adapted for lower temperature levels as part of the regular renewal cycle. In Potsdam, the heating systems installed in the buildings need to be prepared for these lower STs. The intermediate, future STs are published to inform the building owners and to integrate adopting the buildings to lower STs in future investment decisions.

In Springe, the TABs prescribe to implement smart substations that can be controlled remotely to operate the substations and DH grid more efficiently.

In Frankfurt am Main, Jena, Potsdam, and Rostock, flow limiters are implemented at the customer side, and the basic prices are calculated based on the maximum load capacity passing through the substations, incentivising to optimise the heating system.
In Rostock and Springe, heat meters are used to measure the RTs of the customers remotely, and Frankfurt am Main and Jena focus on large customers, enabling identifying high RTs. For creating pressure to act on the RTs, the DH operator in Frankfurt am Main, Jena, Potsdam, and Rostock have or will implement tariffs that incentivise lower and penalise higher RTs. In Henningsdorf, Jena, and Rostock, the DH operators offer a heating service to install, operate and maintain the substations, providing them access to the substations. As radiators are generally oversized, the opportunity to operate the heating systems in the buildings with lower temperatures than the design temperatures is given.
In Henningsdorf, decentral solar thermal heat from customers is to be integrated into the DH grid.

5.3 Operational Transition Management

In the following sections, the ongoing development and implementation of the concepts at the district level, and ongoing projects of implementing remotely readable heat meters and smart substations, lowering the temperature of the DH grid, and testing new forms of participation will be presented.

5.3.1 District Concepts

As stated above, in Frankfurt am Main and Rostock, energy-efficient urban redevelopment concepts are to be developed (Magistrate of Frankfurt am Main, 2021a; Rostock City Council, 2020b). For Frankfurt am Main, a concept for using the excess heat from the commercial area in Fenchenheim-Nord/Seckbach a concept to heat the surrounding residential areas is to be developed (Magistrate of Frankfurt am Main, 2021c). For Rostock, possibilities to gain funding from BAFA for developing the transition plan for the pilot district are to be examined, afterwards, a funding application is to be made (Interview 11). In Drewitz, the energy-efficient refurbishment is still ongoing, coordinated by the Arbeitskreis StadtSpuren between the housing associations (Interview 9). In Krampnitz, the development of a new DH grid having a ST of 50°C and a RT of 30°C is currently ongoing (Potsdam City Council, 2020a). For Schlaatz, an energy-efficient urban redevelopment concept is currently being developed, including lowering the temperature of the existing DH grid (Interview 9). In Springe, the implementation of the energy-efficient redevelopment concepts is ongoing, in which advising building owners on existing funding programmes for connecting to the DH grid and energy-efficient refurbishment of buildings is an essential part (Interview 12).

5.3.2 Projects

The European Energy Efficiency Directive obligates member states to install remotely readable heat meters and to only have remotely readable once by 1 January 2027 (European Energy Efficiency Directive, 2018). In Jena and Potsdam, the heat meters are replaced as part of the regular renewal with smart heat meters that can measure the heat demand, STs, and RTs of the customers remotely (Interview 7 & 8). In Potsdam, customers with smart heat meters receive information on their RT in addition to their heating bill, showing how many times they comply and do not comply with the RT specified in the contract (Interview 8). In Henningsdorf and Springe, as part of the regular renewal cycle and for connecting the buildings to the DH grid, respectively, smart substations that can measure the heat demand, ST and RT remotely and can be controlled remotely to operate the substations and the DH grid more efficiently are installed (Interview 3 & 12; SWS, 2017). An energy portal for customers, displaying their heat demand and the associated CO2 emissions will be developed (Interview 12; SWS, undated c). In the next heating season, the data from the smart substations will be used to analyse patterns of heat consumption. For large customers, a control strategy for the smart substations is to be developed to shift or stretch their peak demand. (Interview 12)

In Henningsdorf and Jena, concrete short-term action to lower the temperature of the DH grid is planned. In Henningsdorf, the project "Heating Hub" will increase the share of renewable and excess heat from 50 to 80% by 2022 (SWH & Ruppin Consult, 2017). To decrease the heat losses and enable heat storage without pressure, the ST of the DH grid shall be lowered to 95 °C (Interview 3). For this, the heating installers of SWH will conduct site visits at all connected buildings as part of the yearly maintenance to obtain data on the temperature demand of the installed heating systems, check if the distribution system is balanced correctly, and adjust the operation of the substations accordingly (Interview 3). In Jena, as simulations show that free transport capacities are available in the DH grid, tests will be carried out in the heating period 2021 to lower the ST of the primary grid by ten °C to identify weak points or possible supply bottlenecks (Interview 7).

For better integrating the citizens in the process, new forms of participation are developed and tested in Frankfurt am Main and in the district Schlaatz (Interview 1; Schwarz, 2019). In Frankfurt am Main, a democracy convention will be held to involve citizens in updating the Energy and Climate Protection Concept (Interview 1; Magistrate of Frankfurt am Main). In Schlaatz, sustainable visions will be developed together with local citizens using extensive participation (Interview 9; Schwarz, 2019). The process will be continuously observed, evaluated, and analysed to enable a learning-by-doing approach (Schwarz, 2019).

5.3.3 Partial Conclusion

In Frankfurt am Main, Potsdam, and Rostock, concepts at the district level are or are to be developed. In Potsdam, the ongoing energy-efficient refurbishment process in Drewitz is coordinated between the housing associations by an established working group. The first low-temperature DH grid of Potsdam is to be implemented in Krampnitz. For Schlaatz and a pilot district in Rostock, concepts for lowering the temperature levels of the existing DH grid are to be developed. In Springe, building owners are advised on existing funding programmes for connecting to the DH grid and energy-efficient refurbishment measures.

In Jena and Potsdam, heat meters are implemented as part of the renewal cycle to measure the heat demand, STs and RTs remotely. In Potsdam, the data is used to inform customers on their RT. In Henningsdorf and Springe, smart substations that can measure the heat demand, STs and RTs and can be controlled remotely to operate the substations and the DH grid more efficiently are installed as part of the regular renewal cycle and to connect the buildings to the DH grid, respectively. In Springe, with the data, an energy portal for customers to display their heat demand and associated CO2 emissions, and for large customers control strategies to shift or stretch their peak demand are to be developed.

In Henningsdorf and Jena, concrete action is planned to lower the STs to 95 °C by 2022 and by ten °C, respectively. In the small city Henningsdorf, heating installers from SWH will conduct site visits to obtain data on the heating system's temperature demand, check if the distribution system is balanced hydraulically correctly and adjust the operation of the substations accordingly. In the large city Jena, the STs will be lowered by ten °C, and weak points or possible supply bottlenecks identified.

For integrating stakeholders better in the process, new participation formats in Frankfurt am Main with the democracy convent and, in the district Schlaatz, creating sustainable visions with the local citizens, are tested.

5.4 Reflexive Transition Management

The following section will present the experiences stated by the practitioners regarding specific projects and involving actors in the process, the monitoring and controlling strategies, and the framework conditions seen as necessary for the transition.

5.4.1 Experiences

The experiences gained in developing a sustainable commercial area in Frankfurt am Main, of lowering the temperatures of the DH grid in the pilot district in Rostock and in the three districts in Potsdam shall be used for similar projects in the respective city (Interview 11; Magistrate of Frankfurt am Main, 2021c; Potsdam City Council, 2020b). In Potsdam, the experiences gained from developing a new low-temperature DH grid in Krampnitz will be used in the process of lowering the temperature of the existing DH grids (Potsdam City Council, 2020a). The new DH grid and the existing DH grid shall have the same ST and RT in the future (Potsdam City Council, 2020a). As a lesson learned from Drewitz, greater emphasis is placed on public relations and participation of the local citizens in the development of the concepts in Drewitz (Interview 9).

In Rostock, the experiences from developing the Heat Plan show that more time is necessary and that the Heat Plan will not describe the way to a fossil-free heat supply but an interim status, making further investigations on the district level and available heat sources necessary (Interview 10). The experiences show further that the knowledge on the heat transition is not that great and that more communication on the topic is crucial for motivating the actors to contribute (Interview 10). Involving external experts and demonstrating the technical implementation can help convince people that the strategy is sensible and feasible (Interview 8 & 10). Experiences from stakeholder meetings show that only the people already interested in the topic can be reached with these events and not the broad mass (Interview 1 & 3). Experiences, however, also show that there are building owners and customers that are not that interested in the topic (Interview 2, 8, 10 & 12). For better involving the actors in the process, new ways need to be found (Interview 1 & 8). In a strategy workshop at EWP, the idea came up to accompany the customers - including their heating system - as a service provider (Interview 8).

5.4.2 Monitoring and Controlling Strategy

Monitoring enables observing and reporting the overall and activity-specific progress. Controlling allows to evaluate the process, deriving further activities and adjusting the process, if necessary. (Hertle et al., 2018)

For Frankfurt am Main, Potsdam, Rostock, and Jena, the progress on implementing the measures written in the climate protection and sustainability strategy, respectively, will be regularly reported. For Frankfurt am Main, a report every two years describing the undertaken climate protection measures and a report every five years on the status of the Master Plan 100% Climate Protection measures are written (Magistrate of Frankfurt am Main, 2021a). For Potsdam, a progress report is written at the end of the two years for the measures listed in the Action Programme (Potsdam City Council, 2020c). For monitoring the goal to reduce the GHG emissions by 95% compared to 2019, the city administration and municipal companies in Rostock have to report every three years on specific parameters and measures planned for the next three years (Rostock City Council, 2020a). For Jena, the implementation of the sustainability strategy shall be monitored every two years (Interview 6).

For Frankfurt am Main, the Energy and Climate Protection Concept, representing the basis for action on climate protection, will be evaluated soon (Interview 1; Magistrate of Frankfurt am Main, 2021a). For Henningsdorf, a sustainability strategy is to be developed (Henningsdorf City Council, 2020b). For Potsdam, the Master Plan 100% Climate Protection should be evaluated every six and the Action Programme developed every two years (City of Potsdam, 2018; Interview 9; Potsdam City Council, 2018a). For Jena, the sustainability strategy shall be evaluated every two years (Interview 6).

For the heat transition specifically, a monitoring and controlling strategy will be developed for the Heat Plan in Rostock (Zander & Hempfling, 2020). For the energy transition, the concept of reaching 80%, preferably 100% renewable energy supply by 2040 in Jena is to be evaluated every five years (City of Jena, 2020). For the energy utilisation plan in Potsdam and the heat map in Rostock, the aim is to update the data in cooperation with the Stadtwerke continuously and possibly use data from funding programmes (Interview 9 & 10).

5.4.3 Framework Conditions for the Transition

For a successful transition, more personnel resources to facilitate and coordinate the process, conduct energy consulting, and implement energy-efficient refurbishment measures are necessary (Interview 1, 4, 9, 10 & 12; Magistrate of Frankfurt am Main, 2021a).

Economic calculations show that using renewable and excess heat sources in the DH grids is more expensive than natural gas (Interview 1, 3, 8 & 11; Schöttke et al., 2016). However, for reaching a climate-neutral building stock, the question should not be the cheapest heat supply, but the cheapest heat supply using renewable and excess heat (Interview 1). In Henningsdorf, converting the DH to an 80% climate-neutral heat supply resulted in a price increase of 13% for the customers, leading to discontent and debates about the socially acceptable price level of heating (Interview 3). The practitioners state that having reliable, supportive economic framework conditions and gaining sufficient funding for planning and implementing renewable and excess heat technologies are crucial (Interview 2, 3, 7, 8 & 12). For integrating low-temperature excess heat sources, the practitioner from Energiereferat in Frankfurt am Main states that new innovative ways and ideas to finance the DH grid need to be developed and tested and that allowing third parties to feed heat into the DH grid could accelerate the transition (Interview 1). In the Heat Plan of Rostock, the idea came up to involve citizens financially to increase the acceptance and enhance the public awareness (Interview 10 & 11).

The practitioners state that the landlord-tenant dilemma needs to be solved and that economic instruments and legal requirements need to be aligned to the goal of climate neutrality, creating pressure to act (Interview 1, 4, 5, 8, 9, 10, 11 & 12). The practitioner from the climate protection department in Potsdam states that due to the lack of an adequate legal framework, the municipal goals must be incorporated individually in every construction project, being very time-consuming and personnel-intensive (Interview 9).

5.4.4 Partial Conclusion

In Frankfurt am Main, Rostock, and Potsdam, the experiences made on the district level with implementing technical solutions and integrating actors in the process, shall be used for similar projects in the city.

In Rostock, the experiences show that more time is necessary to develop a concept on reaching a fossil-free heat supply and that the knowledge level on the heat transition is not that great. Involving external experts and demonstrating the implementation can help convince actors that the strategy is sensible and feasible. With stakeholder meetings, only the people already interested in the topic can be reached and not the broad mass, highlighting the importance to find new ways to approach better and involve actors.

In Frankfurt am Main, Potsdam, Rostock, and Jena, the progress on implementing the measures written in the climate protection and sustainability strategy will be regularly reported, and the strategies for Potsdam and Jena evaluated every two years. The concept of reaching 80%, preferably 100% renewable energy supply by 2040 in Jena shall be evaluated every five years. A monitoring and controlling strategy is to be developed for the Heat Plan in Rostock. In Potsdam and Rostock, the data of the energy utilisation plan and the heat map, respectively, shall be updated continuously.

For a successful transition, more personnel resources to facilitate and coordinate the process, conduct energy consulting, and implement energy-efficient refurbishment measures are necessary. Furthermore, reliable, supportive framework conditions must be established. These framework conditions include solving the landlord-tenant dilemma and aligning the economic instruments and legal requirements to the goal of climate neutrality to create pressure to act. For the transition, developing new innovative ways to finance the development of the DH grids need to be found.

6 Discussion

The following section will reflect on the applied theory and methods used to examine the transition process of lowering the ST of existing DH grids located in the case municipalities. The key findings will be shortly discussed and derived recommendations are presented.

6.1 Theory and Methodology

The Master thesis aims to study the process of lowering the temperature of existing DH grids in their real-life context. By identifying the municipalities that aim to lower the ST of the DH grids located in the municipality, it became apparent that a general overview of existing DH grids, their current temperature levels and DH operators pursuing this target is lacking. Conducting a study on which DH operators aim to lower the ST significantly gives the municipalities and DH operators further contacts to exchange experiences and lessons learned on the topic.

The size of the studied case municipalities, ranging from small to major cities, and the degree of expansion of the DH grid, ranging from currently being developed to supplying around 80% of the households, enables to indicate different approaches based on the size and the status of the development process for the case municipalities.

For answering the research question, data obtained from existing documents and semi-structured interviews conducted with the DH operators and the climate protection departments of the case municipalities, and the redevelopment manager for Springe, are analysed. Another key actor in the transition, as stated in the *Problem Area*, are the building owners (Riechel & Koritowski, 2016). The practitioner from Mainova states that some customers already asked for low-carbon heating solutions. In Hildesheim-Drispenstedt, for example, the impetus for energy-efficient refurbishment came from the municipal housing association, lowering together with the DH operator the temperature of the DH grid to decrease the heating losses and better integrate solar thermal sources (BMU et al., 2017). Regarding the integration of the building owners in the process, the Master thesis focuses on the regulatory and economic measures set by the DH operator and on the organisational structures between local citizens, housing associations, the municipality, and the DH operator, including energy consultancy.

The Master thesis aims to explore the topic and develop ideas for further studies. Conducting an individual case study, for example, for Potsdam as Potsdam has the most ambitious goal for lowering the temperature of the DH grid among the studied case municipalities, could explore further how the various actors within and outside of the municipal administration are integrated into the process.

In the Master thesis, the process of lowering the temperature in the six case municipalities is explored, taking transition management as a theoretical lens to collect and analyse the data.

Collecting and analysing data through a theory lens adds depth and insights by providing conceptual understandings of the complex real-world (Reeves et al., 2008; Yin, 2018). Lund et al. (2018, p. 617) highlight a high level of understanding of dealing with the technical aspects of low-temperature DH grids utilising renewable and excess heat sources, the "*primary current challenge seems to be the understanding of the implementation*". Applying transition management as a theoretical lens in the Master thesis provides a different perspective on a rather technical field by having a socio-technical perspective on structuring multi-actor process. Following the theory of transition management, the four different types of governance activities, namely strategic, tactical, operational and reflexive, were adapted in the Master thesis to the process of lowering the temperature of existing DH grids based on the previously read literature and the data collected and examined. One part of the reflexive governance activities, was to ask the practitioners, where they would like to have more support to identify the framework conditions that need to be changed. As overcoming these structural barriers is essential, and cities can play an important in influencing the discourses as change agents, further investigations should include this aspect (Hölscher & Frantzeskaki, 2021).

For this, the transition management approach is adopted to the process of lowering the temperature of the existing DH grid based on literature read beforehand and the data collected in the Master thesis. The practitioners are asked where they would like to have more support to identify the framework conditions that need to be changed, excluding how the case municipalities seek to influence the state and national framework conditions. As overcoming these structural barriers is essential, and cities can play an important role as change agents influencing the discourse, further investigations should include this aspect (Hölscher & Frantzeskaki, 2021; Loorbach, 2007).

6.2 Key Findings and Derived Recommendations

Germany has recently set the goal to become climate-neutral by 2045. For reaching this target, all sectors, including agriculture, buildings, energy industry, industry, transport and waste management, and all municipalities in Germany have to develop and align their strategies to the goal (BMU, 2021; Paar et al., 2010). The case municipalities have developed climate protection concepts with various targets for the time horizon 2030 or 2050. Frankfurt am Main, Potsdam and Rostock have developed climate protection concepts with the same specifications set in the Master Plan 100% Climate Protection framework. In Potsdam, a sub-concept for a climate-neutral DH grid and in Frankfurt am Main, measures to transform the DH grid are listed, while in Rostock, no analyses for the future development of the DH grid were undertaken in the Master Plan 100% Climate Protection from 2014. The practitioner from the climate protection department in Rostock states that the perception of climate change has changed significantly since then and that climate change is now seen as an urgent, essential task. Experiences from developing the Heat Plan show that integrating actors can motivate them to contribute actively and reveal willing and unwilling actors. As climate protection is a cross-sectional task, cooperation between politics, municipal administration, economic and civil society actors is necessary (Riechel et al., 2017). Furthermore, as municipal administrations tend to have clear allocations of responsibilities and division of labour, it is crucial to organise cross-departmental exchange and cooperation (Riechel et al., 2017). The process of developing a new or updating the existing climate protection concept can be used to include actors from within and outside the municipal administration in the transition arena, as seen in Jena, and to include further actors in the extended transition arena, as seen in Frankfurt am Main. The development of the sustainability strategy in Henningsdorf and the evaluation of the climate protection concepts in the other case municipalities should be used to include further as relevant identified actors in the process. The practitioners from the case municipalities state that further personnel resources for coordinating, facilitating and evaluating the process are necessary. Furthermore, more personnel resources are necessary for conducting energy consultancy, and more trained craftsmen to implement the process (Maaß et al., 2021; Thamling et al.,2020).

Due to the long investment cycles of the energy industry and especially the housing industry of 30 to 40 years, today's investment decisions need to be aligned to the long-term goal to avoid stranded assets (Maaß et al., 2021). For this, the framework conditions need to be aligned to the goal of climate neutrality (Thamling et al.,2020).
For Frankfurt am Main, Henningsdorf, and Rostock, heating concepts for decarbonising the SH and DHW preparation, and for Jena, Potsdam, and Springe, on decarbonising the DH grid were or are developed. These concepts are or were developed within the framework of funded projects or to comply with the legal obligations, highlighting the importance of having a context to develop them. Unlike other countries in Europe, like Netherlands and France, developing municipal heat concepts and concepts for transforming the DH grids is not obligatory nationwide in Germany (Bürger et al., 2021; Thamling et al., 2020). In Germany, only Baden-Württemberg and Hamburg have a legal obligation to conduct municipal heat concepts, and Hamburg and Thuringia to develop decarbonisation concepts for the DH grids (Bürger et al., 2021). For Frankfurt am Main, and Rostock, decarbonisation strategies for the DH grid are to be developed. For Henningsdorf, a concept on reducing the temperatures of the DH grid in the long-term due to the high share of buildings (65%) owned by only two housing associations should be developed.

Due to the long technical lifetime of the substations of 20 or 30 years, determining the future temperature levels of the DH grid <u>now</u> is crucial to be able to adapt the temperature levels written in the TABs (Lange et al., 2017b). Adjusting the temperature levels in the TABs will ensure that new substations are installed and existing ones are replaced as part of the regular renewal cycle for these design temperature levels.

For developing transition plans for the DH grids, data on the energy efficiency, heating, and temperature demand of installed heating systems are necessary (Averfalk et al., 2017; Deutsch et al., 2019). However, gaining reliable data for heat planning is challenging and time-consuming (Riechel et al., 2017). According to the practitioner from the climate protection department in Rostock, there need to be easier ways to obtain the necessary data for planning than relying on the actors' willingness (Interview 10). Except for Jena, the case municipalities have no right to access data for non-municipal buildings (Bürger et al., 2021). In Hamburg and Thuringia, municipalities have the right to access the available (energy) data, in Baden-Württemberg, the data on the heat demand and used heating technologies on the building level and in Schleswig-Holstein, the data on the energy demand, used heat sources, and further necessary parameters on the district level (Baden-Württemberg Climate Protection Act, 2020; Bürger et al., 2021; Hamburg Climate Protection Act, 2020; Schleswig-Holstein Energy Transition and Climate Protection Act, 2017; Thuringia Climate Act, 2018). In the other federal states, the municipalities depend on the willingness of the actors to provide the data (dena, 2019). Even if the data are provided, there are often inconsistencies between the data sets, requiring a considerable time to resolve them and convert the data from the street to the building level (Riechel & Koritkowski, 2016). For 15 investigated energy-efficient urban redevelopment concepts, on average, 40% of the time is spent on collecting the data for analysing the current status, leaving less time to analyse the potential and deriving measures (Riechel & Koritkowski, 2016). Furthermore, the case municipalities lack the necessary data on the temperature demand of the installed heating systems in the buildings. This data, however, is essential to significantly lower the temperatures of existing DH grids (Averfalk et al., 2017). According to the practitioner from SWJN, the building side is not included in the concept of how to reach a nearly climate-neutral DH grid by 2040 due to a lack of data, highlighting the importance of supporting DH operators in collecting the data. Not only for planning but also for monitoring the process, easier ways to obtain the necessary data need to be developed.

On the other hand, conducting site visits to gain the necessary data, can, as experiences from Swedish DH operators show, improve the relationship between the customer and the DH operator (Månsson et al., 2019). A close and good relationship is identified as an essential aspect for lowering the temperatures of DH grids (Leoni et al., 2020). In Henningsdorf, heating installers will conduct site visits at all customers to see where the temperature limit of reducing the ST lies and if the heating systems are balanced correctly. In Albertslund, a small city located in Denmark in which the DH operator supplies around 7500 customers, the DH operator conducted site visits and developed a catalogue with standard solutions and, through energy consulting schemes, tailored solutions for specific buildings to prepare the buildings for ST of 60°C (Krogh Skjølstrup, 2019). The site visits to be conducted in Henningsdorf should also be used to identify the possibilities to reduce the temperature levels in the long-term future to develop a long-term concept.

Another critical aspect of improving customer relationships is providing transparent information on tariffs and prices (IRENA & AAU, 2021). Transparent information is crucial as many customers in Germany see the DH prices critically due to the unregulated natural monopoly position and as it is often unclear what is made with the profits (Sandrock et al., 2020). For flow- or RT-dependent tariff systems, providing information on improving the heating systems and the reason behind implementing the tariff systems is crucial, as provided by Mainova, for example, with a guide for optimising the heating system and adjusting the maximal flow rate (Leoni et al., 2020). DH operators usually only have access to the substations, if at all (Buffa et al., 2021). For reducing the RTs, however, access to the installed heating systems is crucial (Buffa et al., 2021). Furthermore, experiences show that a close and good relationship with the customers is crucial for lowering the temperatures, making the consideration of EWP to accompany the customers - including their heating system - as a service provider very sensible (Leoni et al., 2020).

For supplying the heat with renewable and excess heat sources, the heat demand and the available heat sources need to be considered together (Lund et al., 2014). For this, the technical potential of the renewable and excess heat sources for the municipality should be analysed (Ministry of the Environment, Climate Protection and the Energy Sector Baden-Württemberg, 2020). For Henningsdorf, the assessment of the available heat sources focused on the current techno-economic potential. As the economic framework conditions need to change to reach climate neutrality, the technical potential should be assessed to be able to analyse the techno-economic potential at a later stage for the changed framework conditions.

As stated in the *Problem Area*, the availability of synthetic fuels and biomass is limited, requiring allocation methods for the usage of these fuels, prioritising their usage for other sectors (Hansen et al., 2019). For Frankfurt am Main, the regional potential for biomass is reduced to take into account that biomass is needed to decarbonise other sectors. Due to the seasonality of the heat demand and the different timely availability of the heat sources, simulations, as conducted in Frankfurt am Main, Henningsdorf, and Rostock, are crucial to determining the potential that can be covered by the available renewable and excess heat sources and to design the size of the heat storage. Furthermore, as seen in Potsdam and Rostock, simulations can determine the future temperature levels of the existing DH grid and free transport capacities, making simulation models an essential tool in lowering the temperature of the DH grid and switching to renewable and excess heat sources (Paar et al., 2013; Lund et al., 2018).

In the case municipalities Frankfurt am Main, Potsdam, Rostock, and Springe, the district level is emphasised as an essential planning level for the heat transition. Also, Riechel et al. (2017, p. 30) highlight the district level in their guideline for municipalities as "*implementation level for the pilot development and testing of new solutions*". The KfW has increased the subsidies for developing energy-efficient urban redevelopment concepts and employing redevelopment managers for three to maximal five years to 75% of the total costs (KfW, 2021a). In combination with funding from the EU and some federal states, like Hesse, Rhineland-Palatinate, Schleswig-Holstein, Thuringia, the remaining costs decrease to 0 to 5% (German Association for Housing, Urban and Spatial Development, 2021). The case municipalities should use this funding to develop (further) energy-efficient urban redevelopment concepts and employ redevelopment managers. The district level can and should be used to concretise the goals, apply technical solutions and new participation formats, reflect on the experiences and use them for developing and implementing similar projects. After the funding period of three to five years, the process, however, is not finished. For continuing the process in the long-term, organisational structures need to be developed, existing ones integrated or the established ones continued, as seen in the districts in Potsdam and the commercial area in Frankfurt am Main (Riechel et al., 2017). As cooperation is crucial for a successful transition, the case municipalities should reflect on the existing structures, develop them further, and set up new ones. From the interviews, it became apparent that ways need to be found to involve the local craftsmen better.

Focusing also on other aspects of the district concepts can generate synergies and help integrate the citizens better. To support this integrated approach, the KfW provides long-term loans and investment grants of up to 40% in connection with an energy-efficient urban redevelopment concept for developing energy-efficient water supply and sewage system, climate-friendly mobility, and green infrastructure (KfW, 2021b). Other relevant aspects for the district should be included in the concept for generating synergies and better integrating the citizens.

Investigations for the case municipalities show that the heat demand must be significantly decreased to cover as much of the heat demand with available renewable and excess heat sources or reach a (nearly) climate-neutral building stock. To significantly decrease the heat demand, all case municipalities should monitor the renovation rate and depths and reflect on the existing structures for energy consultancy and develop the necessary organisational structures. Considering recommendations and experiences from other projects and municipalities can inspire and utilise their lessons learned. In the BMWi-funded project "3% plus", barriers and potential for significantly increasing the renovation rate at the district level were identified in three municipalities (Freudenberg et al., 2019). Due to the wide range of building owners, a targeted and active approach, integrating various multiplicators, is seen as crucial (Freudenberg et al., 2019). For the initial consultancy, the development of a neutral consulting institution without the intention to sell is seen as crucial for the recognition and the trust of the building owners (Freudenberg et al., 2019). For accompanying the building owners from the initial consultancy to the implementation and monitoring, developing an advisory network is seen as sensible (Freudenberg et al., 2019). Modernisation measures or the change of tenants or building owners can provide significant opportunities for energy-efficient refurbishment measures (Freudenberg et al., 2019). However, even in Springe, the smallest case municipality, relevant information on the timing of the change and modernisation cycles is lacking. Therefore, the redevelopment manager in Springe states that individual renovation roadmaps are a sensible measure. In the “3% plus” project, the individual renovation roadmap for single buildings was further developed into a district renovation roadmap and will be tested from 2019-2021 in four municipalities (Freudenberg et al., 2019). In Šabac in Serbia, the DH operator will offer energy performance contracting (IRENA & AAU, 2021). Furthermore, the DH operator can increase the economic incentives for heat savings by increasing or even switching to a 100% variable tariff (Djørup et al., 2020).

Experimenting and developing new ideas on how to better integrate the various actors in the process and learning from the experiences is crucial for the desired change (Riechel et al., 2017). Exchange with other municipalities on the topic can provide an additional perspective and knowledge and stimulate reflection, crucial for the social learning process (Loorbach, 2007; Riechel et al., 2017). However, initial research has shown that the knowledge exchange between the municipalities on the topic is not that great. Learning from and with each other is sensible, and structures to facilitate this should be expanded.

Many of the case municipalities have just started the process of lowering the temperature of the existing DH grid. Studying the process of lowering the temperatures in a few years could reveal more strategic, tactical, operational, and reflexive aspects of the topic.

7 Conclusion

Through multiple case study as research design, the Master thesis examined how the process of lowering the temperatures of existing DH grids is managed in six selected case municipalities, focusing on the DH operator as operator of the system and the climate protection department as the coordinator between the various actors. The studied case municipalities include Frankfurt am Main, Henningsdorf, Jena, Potsdam, Rostock, and Springe. For analysing the transition process, existing documents are analysed and 12 semi-structured interviews conducted with practitioners from the DH operators and climate protection departments located in the six case municipalities, and in case of Springe, with the redevelopment manager. The data is collected and analysed by using transition management as a theoretical lens.

All case municipalities have developed or are developing heating concepts as part of funded projects or to comply with the legal requirements. Detailed data on energy efficiency and on the temperature demand of the heating systems installed in the buildings is lacking. For the potential of renewable and excess heat sources, the potential was or is assessed focusing on the whole city, or at specific sites like in Jena, or on the techno-economic potential like in Henningsdorf.

The City Councils of Frankfurt am Main and Potsdam decided to use 100% renewable and excess heat sources for heating by 2050 and in Henningsdorf, to make necessary replacement investments in CO2-neutral heat generation facilities for the DH grid. For Rostock and Springe, a concept for a fossil-free SH and DHW preparation and for supplying the DH grid with locally available renewable and excess heat sources, respectively, are currently developed with the aim of having a political resolution to implement them. Except for the development of the Heat Plan in Rostock, these heating concepts for the city level are mainly developed by the DH operator or the climate protection department with or without external experts.

For Jena and Potsdam, future long-term ST and RT levels of the DH grid have been determined using simulations and tests. In Jena, as simulations show that free transport capacities exist in the DH grid, test will be conducted to lower the ST by ten °C. Owing to a lack of data, the concept currently being developed on a nearly climate-neutral DH for Jena will not include the building side. For Potsdam, the future ST are 80°C for the primary and 50°C for the secondary DH grids. The determined temperature levels in Jena and Potsdam are included in the TABs to build new substations with these design parameters and adapt existing ones as part of the regular renewal cycle. In Potsdam, the intermediate, future temperature levels are published to inform building owners and enable them to integrate adopting their building to lower STs in future investment decisions. In Henningsdorf, the ST of the DH grid are to be lowered to 95 °C until 2022. For this, heating installers from SWH will conduct site visits to adjust the operation of the substations. For the other case municipalities, concepts will be developed, determining the long-term targets for the temperature levels. In Springe, the aim is to first connect as many buildings and then lower the RT and ST using existing funding programmes. For creating pressure to act on the RTs, Frankfurt am Main, Jena, Potsdam and Rostock implemented basic prices depending on the maximum flow passing through the substation, incentivising to optimise the heating system, and have or have plans to implement tariffs that incentivise lower and penalise higher RTs. In Henningsdorf, Jena and Rostock, the DH operators offer heating services, providing them access to the substations and the opportunity to operate the heating systems in the buildings with lower temperatures than the design temperatures as radiators are generally oversized.

For informing and advising building owners on the energy-efficient refurbishment of their buildings, energy consultancy is offered by all DH operators, in the large cities also the Consumer Centres, in Frankfurt am Main, by a founded non-profit organisation, and in Springe, by the redevelopment manager for the areas covered by the district concepts.

In Frankfurt am Main, Potsdam, Rostock and Springe, the district level is emphasised as an essential planning level. Concepts on the district level enable to concretise targets for the whole city, develop and implement models and technical solutions, test new participation formats, integrate other aspects and establish organisational structures. In Potsdam, the first low-temperature DH grid will be developed in a district and the temperature of the DH grids are first to be lowered in individual parts of the DH grids. In Rostock, the concept for lowering the temperature of the existing DH grid shall be first developed for a pilot district. In one district in Potsdam, sustainable visions are developed together with local citizens to better involve them. Integrating other aspects in the concepts, like green spaces and renewing the water supply, can generate synergies and enable to address the local citizens better. For coordinating between the actors, redevelopment managers were or are to be employed. In Frankfurt am Main and Potsdam, established working groups involved in the process and new organisational structures are created to develop the district together. In Frankfurt am Main, Potsdam, and Rostock the experiences gained in the districts are to be used in similar projects in the city.

In Frankfurt am Main, Potsdam, Rostock, and Jena, the progress on implementing the measures written in the climate protection and sustainability strategy will be regularly reported and the strategies for Potsdam and Jena evaluated every two years. For the maps developed for Potsdam and Rostock, spatially showing the heat and energy demand, respectively, the aim is to continuously update the data.

For as successful transition, more personnel resources and having reliable framework conditions that are aligned to the goal of climate neutrality are seen as crucial by the practitioners. Furthermore, developing new ways of financing and finding new ways to approach and involve the actors better is seen as essential.

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Appendixes

Appendix A: Interview Guides

At the beginning of the interviews, the aim of the Master thesis is presented, the demand for expert knowledge on the specific field highlighted, and the gratitude for participating in the interview expressed (Przyborski et al., 2013). After this introduction, permission is asked to record the interview (Galletta, 2013).
At the end of the interviews, the gratitude was expressed again, and the interviewees asked if it is possible to ask further questions via email if necessary.

The interview guides used for the individual interviews are presented below.

Interview 1: Climate Protection Department Frankfurt am Main

1. Short introductory questions:
    a. what is your educational background?
2. Strategic Transition Management:
    a. has the Master Plan 100% Climate Protection provided the impetus for considering the temperature levels of the DH grids?
    b. has the future temperature level of the DH grid been analysed further as stated in the "Hotmaps" project?
    c. what other aspects are you considering when developing the energy concepts at the district level?
3. Tactical Transition Management:
    a. in the "Hotmaps" project it said that you want to develop a heating strategy together with Mainova?
    b. have five-year goals been set to increase the share of renewable and excess heat in the DH grid as stated in the Master Plan 100% Climate Protection?
    c. how are the districts for energy concepts selected?
    d. do you plan to expand the legal obligations existing in two construction areas to connect and use the DH grid after an energy concept was developed and a contract with Mainova signed to ensure reliable prices?
4. Operational Transition Management:
    a. do you plan to continue or even expand the EU project ACE retrofitting to other groups?
    b. has the ownership map been developed to be able to contact the building owners directly?
5. Reflexive Transition Management:
    a. what have you learned from your experiences so far?
        i. regarding the involvement of actors?
    b. where would you like to have more support?

Interview 2: Mainova

1. Short introductory questions:
    a. what is your educational background?
    b. what is your position at Mainova?
2. Strategic Transition Management:
    a. do you plan on analysing the current status regarding the substations and the heating systems in the buildings?
3. Tactical Transition Management:

a. how are you revising and concretizing the roadmap developed in the "Hotmaps" project?
b. have the ST and RT levels been lowered in the new TABs?
c. have you already identified areas in which the temperatures can or should be lowered first?
d. do you have plans to expand the bonus-malus system also to smaller customers? Is the system helpful for lowering the RTs?
e. why did you stop offering service agreements?
f. do you cooperate or offer training for the local heating installers?

4. Operational Transition Management:
   a. are you already measuring the ST and RT of every customer remotely?
5. Reflexive Transition Management:
   a. what have you learned from your experiences so far?
      i. regarding the involvement of actors?
   b. where would you like to have more support?

Interview 3: Stadtwerke Henningsdorf

1. Short introductory questions:
   a. what is your educational background?
   b. what is your position and role at Stadtwerke Henningsdorf?
2. Strategic Transition Management:
   a. what was the impetus to increase the share of renewable and excess heat sources and reduce the temperatures of the DH grid?
   b. who was involved in developing the future vision?
   c. how did the goal of a CO2-free DH grid 2050 come about?
   d. do you have plans to lower the temperatures further in the future (beyond 2022)?
   e. have you assessed the geothermal potential?
3. Tactical Transition Management:
   a. do you offer service agreements to implement and maintain the substations?
   b. in the project "CO2-free Heat Supply 4.0" a communication strategy and roadmap has been developed. How do they look like?
   c. should the RT be lowered? And if so, how?
4. Operational Transition Management:
   a. in the project "Heating Hub" it said that you do not have so much information on your grid. Do you have a plan to roll out smart heat meters?
5. Reflexive Transition Management:
   a. what have you learned from your experiences so far?
      i. regarding the involvement of actors?
   b. where would you like to have more support?

Interview 4: Climate Competence Centre Henningsdorf

1. Short introductory questions:
   a. what is your educational background?
2. Strategic Transition Management:
   a. Have different heat demands been considered in the sub-concept "CO2-free Heat Supply 4.0" for 2050?
   b. was lowering the temperature a topic in the sub-concept and if so, how was it considered?
3. Tactical Transition Management:
   a. why is the topic of climate protection external and not located in a municipal department?
   b. is there a central contact for energy consulting?

    c. in the sub-concept "CO2-free Heat Supply 4.0" a roadmap was developed. How does the roadmap look like in regards to lowering the temperature?
    d. how does the communication strategy developed in the sub-concept look like?
4. Operational Transition Management:
    a. are energy-efficient urban redevelopment concepts currently being developed or will they be developed?
5. Reflexive Transition Management:
    a. should the Climate Protection Framework Concept be evaluated or a new climate protection strategy developed?
    b. what have you learned from your experiences so far?
        i. regarding the involvement of actors?
    c. where would you like to have more support?

Interview 5: Stadtwerke Energie Jena-Pößneck

1. Short introductory questions:
    a. what is your educational background?
    b. what is your position at SWJ?
2. Strategic Transition Management:
    a. how have these temperature levels written in the TABs been identified?
    b. who is involved in developing the concept?
3. Tactical Transition Management:
    a. are you involved in the initiative Energetic Urban Redevelopment 2025?
    b. how should the customer be integrated into lowering the RTs of the DH grid?
    c. how about the consideration of setting up energy performance contracting?
    d. why are you only offering the heating service for substations that have a capacity of over 30 kW?
    e. do you plan to allow third-party access to the DH grid?
4. Operational Transition Management:
    a. have you conducted or do you plan to run more tests like in the district Lobeda to lower the ST?
5. Reflexive Transition Management:
    a. what have you learned from your experiences so far?
        i. regarding the involvement of actors?
    b. where would you like to have more support?

Interview 6: Climate Protection Department Jena

1. Short introductory questions:
    a. what is your educational background?
2. Strategic Transition Management:
    a. who was involved in developing the Sustainability Strategy?
    b. are you involved in developing the concept of a nearly climate-neutral DH supply by 2040?
    c. do you plan on developing heat analysis and heat concepts?
    d. are you or have you developed energy-efficient urban redevelopment concepts in combination with DH?
3. Tactical Transition Management:
    a. is there a central contact for energy consulting?
    b. are you involved in the initiative Energetic Urban Redevelopment 2025?
    c. was the cooperation in the initiative Energetic Urban Redevelopment 2025 with the Stadtwerke Jena different than in prior concepts?
4. Operational Transition Management:
    a. what projects were developed within the initiative Energetic Urban Redevelopment 2025?

5. Reflexive Transition Management:
    a. should the Climate Protection Concept be evaluated or is the Sustainability Strategy the core document for climate protection now?
    b. is there a monitoring and controlling strategy for the Sustainability Strategy?

Interview 7: Stadtwerke Jena Netze

1. Short introductory questions:
    a. what is your educational background?
    b. what is your position at SWJ?
2. Strategic Transition Management:
    a. do you plan on developing heat analysis and heat concepts?
    b. who is involved in developing the concept for a nearly climate-neutral DH supply in 2040?
    c. is lowering the temperatures of the DH grid a topic in the concept and if so, how?
    d. are the temperature levels written in the TABs the future temperature levels you aim for in 2040?
    e. will the concept consider the building side?
    f. has the potential for geothermal and excess heat been analysed?
3. Tactical Transition Management:
    a. have you identified the first district in which the temperatures of the DH grid shall be lowered?
    b. do you plan to develop your own renewable and excess heat facilities or in cooperation with the TEAG or allow third-party access?
4. Operational Transition Management:
    a. are you already measuring the ST and RTs of every customer remotely?
    b. have you conducted or do you plan to run more tests like in the district Lobeda to lower the ST?
5. Reflexive Transition Management:
    a. what have you learned from your experiences so far?
        i. regarding the development of the concept?
        ii. regarding the lowering of the temperatures?
    b. where would you like to have more support?

Interview 8: Energie und Wasser Potsdam

1. Short introductory questions:
    a. what is your educational background?
    b. what is your position at EWP?
2. Strategic Transition Management:
    a. has the Master Plan 100% Climate Protection provided the impetus for considering the temperature levels of the DH grids?
    b. how did you identify the future temperature levels written in the TABs?
3. Tactical Transition Management:
    a. do you offer heating services to your customers?
    b. how are the local heating installers involved in the process?
    c. how should the customers be integrated into lowering the RTs?
    d. how is the partnership agreement in Krampnitz? Should it be expanded to further districts by founding municipal district-related companies?
    e. do you use your energy performance contracting to prepare buildings for lower STs?
    f. in the sub-study “Climate-neutral DH” the concept of developing an open heat platform is mentioned. Has the concept been further developed?
4. Operational Transition Management:
    a. are you already measuring the ST and RT of every customer remotely?

5. Reflexive Transition Management:
    a. what have you learned from your experiences so far?
        i. regarding the involvement of actors?
    b. where would you like to have more support?

Interview 9: Climate Protection Department Potsdam

1. Short introductory questions:
    a. what is your educational background?
2. Strategic Transition Management:
    a. which energy/heat sources and how will the heat demand be considered in the energy utilisation plan?
3. Tactical Transition Management:
    a. the Master Plan 100% Climate Protection says that the city will be divided into climate districts. What are you doing in these climate quarters?
    b. how do you continue implementing the energy-efficient urban redevelopment concepts after the funding for the redevelopment manager expires after 3 to 5 years?
    c. is there a central contact for energy consulting?
4. Operational Transition Management:
    a. will the participation concept developed in the project "KlimaKompakt" be applied in the district Schlaatz?
5. Reflexive Transition Management:
    a. Have you already started to develop a controlling tool as stated in the Action Programme?
    b. what have you learned from your experiences so far?
        i. regarding the development and implementation of the three districts?
        ii. regarding the involvement of actors?
    c. where would you like to have more support?

Interview 10: Climate Protection Department Rostock

1. _Short introductory questions:
    a. what is your educational background?
2. Strategic Transition Management:
    a. in the Master Plan 100% Climate Protection it sounded like you would want to use biomass and biogas to decarbonise the DH system. What has changed this?
    b. who is involved in developing the Heat Plan?
    c. has the questionnaire sent out at the beginning played a role in the process of developing the Heat Plan?
    d. does lowering the temperature of the DH grid play a role in the Heat Plan and if so, how?
    e. how has the decision to become climate-neutral by 2035 changed the process?
    f. when developing the energy-efficient urban redevelopment concepts, will the focus be on the energy-efficient refurbishment of buildings and heat supply or also on other aspects?
3. Tactical Transition Management:
    a. how will the citizens be integrated into the implementation of the Heat Plan?
    b. how have you identified districts in which energy-efficient urban redevelopment concepts shall be developed?
    c. is there a central contact for energy consulting?
    d. are you considering allowing third-party access or prosumers?
    e. are you trying to include other sources of financing (other than SWR) in the financing plan?
4. Operational Transition Management:

    a. will energy-efficient urban redevelopment concepts currently be developed?
5. Reflexive Transition Management:
    a. will the controlling of the Heat Plan be linked to the controlling of becoming climate-neutral by 2035?
    b. what have you learned from your experiences so far?
        i. regarding the development of the Heat Plan?
    c. where would you like to have more support?

Interview 11: DH operator Rostock

1. Short introductory questions:
    a. what is your educational background?
    b. what is your position and role at SWR?
2. Strategic Transition Management:
    a. in the Master Plan 100% Climate Protection it sounded like you would want to use biomass and biogas to decarbonise the DH system?
    b. will you model the future temperature levels of the DH grid at a later stage?
    c. the big picture shows the energy system in the future. How will the excess heat from the electrolyser plant be integrated into the DH grid?
3. Tactical Transition Management:
    a. have you identified the first districts in which the temperatures of the DH grid shall be lowered?
    b. have the ST and RT levels been lowered in the new TABs?
    c. roughly how many substations belong to and are operated by SWR?
    d. is there cooperation with or training of the local heating installers for the substations not implemented and maintained by SWR?
    e. my interview partner from the climate protection department said that there are considerations to involve the citizens financially?
4. Operational Transition Management:
    a. are you already measuring the ST and RTs of every customer remotely?
5. Reflexive Transition Management:
    a. what have you learned from your experiences so far?
        i. regarding the development of the Heat Plan?
    b. where would you like to have more support?

Interview 12: Redevelopment Manager Springe

1. Short introductory questions:
    a. what is your educational background?
2. Strategic Transition Management:
    a. what and who gave the impetus to develop a DH grid?
    b. how should the future DH grid look like regarding the temperature levels and the heat sources?
    c. who was involved in developing the energy-efficient urban redevelopment concepts?
    d. are other aspects, like mobility and transformation of the public spaces, considered in the energy-efficient urban redevelopment concepts?
3. Tactical Transition Management:
    a. is there a legal obligation to connect to and use the DH grid?
    b. are the areas of the energy-efficient urban redevelopment concepts designated as redevelopment areas?
    c. how should the customers be involved in lowering the RTs?
    d. do you offer service agreements to implement and maintain the substations?
4. Operational Transition Management:
    a. how are building owners motivated to refurbish their buildings energy-efficiently?

   b. is the goal of lowering the temperatures taken into account when connecting customers to the DH grid?
5. Reflexive Transition Management:
   a. how are you monitoring the renovation rates and depths?
   b. what have you learned from your experiences so far?
      i. regarding the involvement of actors?
   c. where would you like to have more support?

Appendix B: Case Study Frankfurt am Main

Strategic Transition Management

In 2012, the City Council decided that Frankfurt am Main should

- reduce its CO2 emissions by 95% by 2050 compared to 1990 levels,
- reduce the energy demand by 50% compared to 2010,
- and use 100% renewable energy sources (Magistrate of Frankfurt am Main, 2021a).

Half of the renewable energy should be generated from local and the other half from regional renewable energy sources (Prohaska et al., 2020). The Master Plan 100% Climate Protection outlines how these goals can be reached. For the development of the Master Plan 100% Climate Protection two workshops each on Construction, housing & urban planning, Energy supply, and Mobility were held. Representatives of the city administration, including the Energiereferat, City Planning Department, Mobility and Transport Department, the local universities, and the local industry, including the Stadtwerke Frankfurt am Main, Chamber of Commerce and Industry Frankfurt am Main and Frankfurt Economic Development, have participated in these workshops. Primarily results show that the energy-efficient refurbishment can reduce the heat demand of residential buildings by up to 62%, requiring a high renovation depth and a renovation rate that is more than three times as high as the current one. For increasing the renovation rate, various social, financial, and technical obstacles are cited from a research project for Germany. These include the lack of perspective of older building owners, the lack of knowledge about energy consumption and renovation potential, the fear of not being well advised, the necessity of majority decision in condominiums, the renovation is not in the foreground when buying a new property, the landlord-tenant dilemma in which landlord finances but tenants benefit from resulting savings, the lack of financing, the technical restrictions and the need of vacant buildings for full renovations. Due to the energy-efficient refurbishment of buildings, the construction of new DH grids, and the increase of the connection rate and expansion of existing DH grids, DH is envisioned to cover around 50% of the heat demand. Lower temperature levels in the DH grid in the future reduce the heat losses and enable the integration of solar thermal, shallow geothermal, and excess heat. (Fraunhofer IBP, 2015)

In the EU-funded project “Hotmaps”, a heating strategy for 2050 has been developed by the Energiereferat together with consultancies and research organisations. Before the development, the process has been discussed in a stakeholder meeting with representatives from Mainova, AGFW, the city of Frankfurt, and research and consultancy organisations. A heat demand density map was created using spatial data on the construction periods and types of buildings and adjusting

energy indicators for Germany to Frankfurt by heating degree days. For supplying the heat demand with renewable and excess heat sources, the potential amount available for heating purposes has been assessed, considering that biomass shall be prioritised for industrial applications requiring high temperatures, reducing the regional biomass potential, and that solar thermal competes with photovoltaic. An excess heat register has been developed, analysing the temperature level and locally mapping the excess heat from data centres, industry, wastewater, wastewater treatment plant, and river water for the whole city. For different scenarios, hourly heat demand profiles are modelled, and the heat sources available to cover the demand are simulated. The results show that the locally available renewable and excess heat could meet over half of the heat demand. However, in the peak load hours, the potential of using renewable and excess heat is significantly lower. To cover as much of the heat demand with renewable and excess heat, heat demand reductions of 40-50% are necessary. Reducing the heat demand by 53% requires that nearly three-Quarter of the buildings in the city undergo energy-efficient refurbishment. The results show that DH is more cost-efficient than the individual supply of buildings using renewable and excess heat sources. A share of 60-80% of the heat demand covered by DH seems meaningful. (Prohaska et al., 2020)
For developing the decarbonisation strategy freely available data is used (Interview 1; Prohaska et al., 2020). Regarding the availability of data, the practitioner from the Energiereferat states that gaining reliable data for infrastructure planning is very challenging (Interview 1).

For three existing and nine construction areas, the climate protection sub-concept "Renewable Energy" modelled different scenarios for covering as much of the energy demand, including the heat and electricity demand, with local renewable and excess heat as possible (Kobelt & Rochard, 2019). Besides the focus on energy, utilisation concepts for roof areas were developed, taking green roofs, energy, and recreational use into account (Interview 1). The energy concepts show that the energy demand of the new and existing buildings needs to be significantly decreased, requiring higher energy standards than the legal requirements. With 30% of the houses build in passive house standard[7] and 70% build in the KfW 55 standard[8], local energy sources can cover more than 50% of the energy demand self-sufficiently. For the three analysed existing districts, the sub-concept recommends developing energy-efficient urban redevelopment concepts. (Magistrate of Frankfurt am Main, 2021b)
In 2015, the City Council decided to develop the commercial area Fenchenheim-Nord/Seckbach into a model for a sustainable commercial space together with an interdepartmental project group and the local companies. For this, a feasibility study for developing a sustainable commercial area and a climate protection sub-concept were created (Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR), 2019). Besides heating surrounding residential

[7] The Passive House Standard requires buildings to have a yearly heating demand of ≤ 15 kWh/m² and a yearly primary energy demand of ≤ 60 kWh/m² per year (Passive House Institute, 2016)
[8] The KfW 55 Standard requires buildings to have only 55% of the primary energy demand and 30% less transmission losses than the energy-efficient standard of the Building Energy Act requires (KfW, undated)

areas with excess heat, mobility, usage of renewable energy and excess heat within the area, and greening are key topics. (Magistrate of Frankfurt am Main, 2021c)

To better integrate excess heat, especially from data centres - they have an electricity consumption currently of around 1.6 TWh, which will increase in the future - the temperatures of the DH grid shall be reduced. The goal is to prepare the buildings for 45°C ST. (Interview 1)
For the decarbonisation, a sensible overall concept is to be developed, including various heat sources, developing small low-temperature DH grids, and reducing the temperature levels of the existing DH grids. For two emerging areas, the potentials of supplying heat using significantly lower ST in the DH is being assessed. For lowering the temperature levels of existing DH grids, reliable information on the heating systems installed in the buildings is not available. (Interview 2)

Tactical Transition Management

The Master Plan 100% Climate Protection serves as orientation and strategy for action on climate protection (Magistrate of Frankfurt am Main, 2021a).
In the "Hotmaps" project, a decarbonisation strategy for heating households and commercial buildings was developed using freely available data. (Interview 1; Prohaska et al., 2020). The developed strategy will be discussed with Mainova, refined using more accurate data, and a strategy taking 2035 as the time horizon will be created (Interview 1 & 2). A master plan is to be developed, including all stages of the value chain, analysing future temperature levels and showing short-, medium- and long-term measures and discussed with customers, the city, and the local companies. The ST and RT levels written in the TABs are to be reduced based on investigations. (Interview 2)
As stated in the strategy developed in the "Hotmaps" project, the data centre operators shall be convinced to use water for cooling directly to use the excess heat in DH grids. Convincing the data operators to directly cool with water has not been that successful yet, as it is more expensive than using air. (Interview 1)
In the future, district by district will be examined to find the most favourable heat supply options, including decentral and central solutions. On the district level, it will be assessed for the DH grid if it is more sensible from an economic perspective to prepare every building for lower STs or to increase the temperature of the excess heating source using heat pumps. (Interview 1)
Energy-efficient urban redevelopment concepts will be developed in connection with integrated urban development concepts to use the established district management structures. In developing these concepts, the Energiereferat aims to integrate Mainova, the people living in the district, and the housing associations. For implementing the energy-efficient urban redevelopment concepts, redevelopment managers are to be employed. (Interview 1)
To decrease the high costs of building DH grids in existing districts and create synergies between the maintenance of different infrastructures, a platform called "Kommunalregie" has been developed. The road traffic office, the office for information and communication technology (ICT), the Mainova subsidiaries Netzdienste Rhein-Main responsible for operating the water, electricity, gas, and DH grid, and the Stadtentwässerung Frankfurt responsible for the sewage system

developed this map showing the age and quality of the grids. (Magistrate of Frankfurt am Main, 2021a)

For the project "Sustainable commercial area Fenchenheim-Nord/Seckbach", an office consisting of a climate protection manager and a site manager was established within the research project "Experimental Housing and Urban Development" to coordinate, moderate, and organize the processes. After the funding period of five years, a founded initiative consisting of local companies together with the climate protection manager will continue to coordinate the process. (BBSR, 2019; Magistrate of Frankfurt am Main, 2021c)

In 2010, the non-profit association Energiepunkt was founded to improve the quality of energy consultancy, planning, and implementation (City of Frankfurt am Main, undated; Magistrate of Frankfurt am Main, 2021b). From 2016 to 2020, the Energiepunkt was a sub-partner in the EU-funded project "Accelerating Condominium Energy Retrofitting", which aims to increase the energy-efficient refurbishment of condominiums (Magistrate of Frankfurt am Main, 2021a). In the project, the Energiepunkt advised and accompanied condominiums objectively and free of charge from the initial potential analysis over energy consultancy using the individual renovation roadmap as an advisory tool until the implementation and evaluation of the measures (Energiereferat, 2018). The site inspections and individual renovation roadmaps are to be maintained on a smaller scale for the condominiums (Magistrate of Frankfurt am Main, 2021a). Two energy consultants provide independent, free energy counselling for the first 90 minutes about topics related to energy, including, for example, subsidy programmes, energy-efficient refurbishment, and renewable energy supply (Interview 1; Magistrate of Frankfurt am Main, 2021b; City of Frankfurt am Main, undated). Additionally, the Energiepunkt offers further consulting and further during planning, tendering, and implementation of concrete projects for a fee. Furthermore, the Energiepunkt lists craftsmen companies certified by the Chamber of Crafts and have proven experience and quality in constructing passive houses. (Magistrate of Frankfurt am Main, 2021a)
The Consumer Centre Hesse and Mainova also offer energy consulting services (Consumer Centre Hesse, undated; Mainova, undated b).
The city and the municipal housing association AGB Frankfurt Holding take a pioneering role, deciding to construct new buildings as passive houses - or for proven economic reasons with 30% less heating requirement than the energy-feed in regulation requires in the case of the municipal housing association (ifeu, 2008; Prohaska et al., 2020). Furthermore, the passive house standard is aimed for when existing municipal buildings are refurbished and leaseholders and purchasers of municipal land are obligated to construct new buildings as passive houses (ifeu, 2008; Magistrate of Frankfurt am Main, 2021b). For real estate investors, the city developed a subsidy programme to build passive houses and build 30% of the new buildings for social housing (Prohaska et al., 2020).

For the construction areas Preungesheim-Ost and Riedberg, there is a legal obligation to connect and use the DH grid or build a passive house (Interview 1). The option to build a passive house

provides degrees of freedom (Interview 1). For these two areas, energy concepts were developed comparing heating systems based on the levelized costs of heating for the end customer. As these concepts show that the DH grid has similar or even lower costs than other heating systems, the legal obligation to use the DH grid was established, and a contract with Mainova was signed. The contract was signed to make reliable statements about the price development and exclude arbitrariness due to the natural monopoly of the DH grid. (Energiereferat, undated a)
Asked about expanding the legal obligation to other districts, the practitioner from the Energiereferat states that the possibilities will be investigated during the development of the concepts (Interview 1). The practitioner from Mainova says that legal obligations to connect to and use the DH grid and self-commitment from the city to have municipal buildings as anchor customers are crucial as they give the necessary planning security to expand existing or build new DH grids (Interview 2).

The TABs prescribe that the heating system in the building that is to be connected to the DH grid has to be hydraulically balanced by an approved contract installation company and that a flow limiter is to be implemented (Mainova, 2021b). The maximum flow passing through the flow limiter is calculated based on the reported maximum connection load and the in the contract agreed cooling of the RT (Mainova, 2021b). The basic price of the DH tariff depends on the reported maximal connection load of the substation, incentivising customers to optimise their heating system (Interview 1). On the website, a guideline shows how the heating bill can be used to indicate if adjusting the capacity of the substation might make sense and how to proceed then (Mainova, undated c).

At specific grid nodes and larger customers, STs and RTs are measured remotely (Interview 2). For large customers, which account for about 80% of the connected capacity, a bonus-malus tariff has been implemented, incentivising lower RTs and penalising higher RTs than agreed in the contract. By high RTs, reasons for this are examined together with the customer, and measures to reduce the RTs derived. For the implementation, the fact that lower malus prices and if the maximal connection load is reduced, also lower basic prices, is emphasized. Furthermore, possibilities to gain funding from the Federal Office of Economics and Export Control (BAFA) are examined. In specific cases, according to the practitioner, Mainova might even finance the measures. (Interview 2)

At the end of 2019, Mainova stopped offering service agreements to maintain the substations of customers due to economic reasons. For some of the expired service agreements, a commissioned and trained service provider took over. (Magistrate of Frankfurt am Main, 2019; Interview 2)

Operational Transition Management

This year, an application for an energy-efficient urban redevelopment concept is to be submitted (Magistrate of Frankfurt am Main, 2021a).

The first project to use the excess heat from data centres is currently ongoing (Magistrate of Frankfurt am Main, 2021b).
For developing a sustainable commercial area in Fenchenheim-Nord/Seckbach a concept is to be developed for utilising the excess heat in the surrounding residential areas, listing concrete short- and middle-term measures (Magistrate of Frankfurt am Main, 2021c).

The Energy and Climate Protection Concept will be evaluated with extensive citizen participation (Interview 1; Magistrate of Frankfurt am Main, 2021a). A democracy convention as a new participation format is planned this year to better integrate citizens in the process (Interview 1). In the democracy convention, two-Third of the around 60 participants are randomly selected, and one-Third is specifically invited to develop recommendations for actions with the promise that they will be discussed and tried to be implemented (Interview 1; mehr als wählen, 2019).

The City Council decided that the coal-fired CHP plant should only be operated until the middle of the 2020s (Interview 1). The practitioner from Mainova states that a hydrogen-ready CHP plant running on natural gas will be constructed. In the future, hydrogen could be used, provided that it is available, according to the practitioner from Mainova. (Interview 2).

Reflexive Transition Management

Regarding involving actors in the process, the practitioner from the Energiereferat states that cooperating with Mainova and the housing associations is crucial. To increase and deepen the cooperation, more personnel resources in the Energiereferat would be necessary. Experiences from stakeholder meetings show that only the people already interested in the topic can be reached with these events. To better reach and integrate further people, new participation formats, like the democracy convention, need to be developed and tested. (Interview 1)
For addressing the building owners directly, an ownership structure map should be developed (Fraunhofer IBP, 2015). Due to data protection, however, it has not been possible to develop this map (Interview 1). For expanding the advisory service and handling the increasing number of requests, further personnel resources are necessary for the Energiepunkt (Magistrate of Frankfurt am Main, 2021a).
For involving customers in the process, the practitioner from Mainova states that some customers already asked for low-carbon heating solutions and are thankful that measures for reducing the RTs are shown and implement these measures, while others do not (Interview 2).

In the project "Sustainable commercial area Fenchenheim-Nord/Seckbach", a model for a sustainable commercial space is to be developed and the experiences used in similar projects in the city (Magistrate of Frankfurt am Main, 2021c).

Every five years, a report showing the status of the measures described in the Master Plan 100% Climate Protection and every two years, a report describing the undertaken climate protection measures are written (Magistrate of Frankfurt am Main, 2021a). For the overall progress, a report on the development and current status, being 2017, was written (Magistrate of Frankfurt am Main, 2021a). The Energy and Climate Protection Concept, representing the basis for action as the climate protection measures including the budget were decided upon, will be evaluated soon (Interview 1; Magistrate of Frankfurt am Main, 2021a).

Analyses show that heat supply options using local renewable and excess heat are costly and only economically viable compared to fossil fuels with a CO2 price of 300 €/t CO2. For municipal buildings, 50 €/t CO2 are included as costs for CO2, and the practitioner from the Energiereferat says that they plan to increase this to 180 €/t CO2, representing the socio-economic costs suggested by UBA. Mainova, as both a municipality-owned utility and a stock company, makes investment decisions based on economic feasibility calculations. The practitioner from the Energiereferat states that the question, however, should not be the cheapest heat supply, but what is the cheapest heat supply using renewable and excess heat for the area. Regarding hydrogen, the practitioner from the Energiereferat states the fear that hydrogen is taken as an easy way to convert from natural gas to renewables without taking the limited availability and high prices into account. The practitioner fears that relying on hydrogen prevents undertaking investments today that would make heating cheaper in the future. According to the practitioner, for exploiting the excess heat potential, new innovative ways and ideas to finance the DH grid need to be developed and tested. The practitioner added that the liberalisation of the DH grids could accelerate the transformation by opening the DH grid for third-party access. (Interview 1)
For the transition, the practitioner from the Energiereferat further states that legal frameworks generating pressure to act, such as banning fossil fuels or requiring data centres to cool with water, are necessary (Interview 1). The energy concepts developed for the 12 districts show that higher energy efficiency standards are necessary to cover as much of the demand with local renewable energy and excess heat sources (Magistrate of Frankfurt am Main, 2021b).
The practitioner from Mainova expresses the importance of having reliable, regulative framework conditions and the commitment from the city (Interview 2).

Appendix C: Case Study Henningsdorf

Strategic Transition Management

In 2006, the prices for oil and gas were souring up with annual increases of 20-30% in fuel prices from one year to the next. There were no signs at the time that there might be a phase of price stabilisation. This price increase and the discussion of the shortage of fossil fuels lead to the focus on regional heat sources. In 2006, the executive management of SWH brainstormed future heating technologies together with two engineering companies and an accountant to include both the technical and the economic sides. The considered heating technologies included geothermal heat and heating and CHP plants using fossil fuels, like coal and natural gas, and regenerative fuels, like biogas and wood. Eventually, it was decided to build a CHP plant running on wood chips. (Interview 3)

In the same year, Henningsdorf City Council discussed the long-term investment strategy of SWH and decided that necessary replacement investments should be made in CO2-neutral heat generation facilities in the future (SWH, 2018). With the 2009 build biomass CHP plant and the 2011 build biomethane CHP plant, around 54% of the heat demand is supplied by regional, regenerative heat sources (Bethke, 2019; Henningsdorf City Council, 2017).

The Climate Protection Framework Concept states that coupling the DH, electricity, and gas grid is crucial for a future energy system mainly based on fluctuating renewable electricity. The DH grid can provide flexibility for the electricity grid through heat storage that enables to operate the (existing) CHP plants more according to the electricity grid and through Power-to-heat that converts excess electricity into heat. (B.A.U.M. Consult, 2015)

As there is hardly any potential available to increase the use of local biomass in the future, the economic feasibility of other heat sources, like geothermal heat, solar thermal, excess heat, and Power-to-heat together with heat storage need to be assessed (B.A.U.M. Consult, 2015; SWH & Ruppin Consult, 2017; Interview 3). Former drillings show that geothermal heat with temperatures of around 100°C exists in 4,000 m (Interview 3).

To increase the share of renewable and excess heat to 80% by 2022, SWH started a lighthouse project, called “Heating Hub”, in 2016 to integrate solar thermal and excess heat. In the first phase of the “Heating Hub”, SWH developed a techno-economic concept with consultancies. For this, simulations for different loads were carried out to identify possible bottlenecks and optimisation measures in the DH grid and at the customer side for integrating fluctuating heat sources from various locations. Furthermore, the techno-economic potential of integrating excess heat from the local steel plant and decentral and central solar thermal were assessed. Based on these results, simulations of the DH grid to design the size of the heat storage to integrate the fluctuating solar thermal and excess heat better were conducted. (SWH & Ruppin Consult, 2017)

For increasing the share of renewable and excess heat even further, the techno-economic potential of building an electrode boiler to convert excess electricity into heat has been assessed in the “WindNODE” project (Interview 3).

For the Climate Protection Framework Concept, a heat register was developed based on DH consumption data on street level and for the other buildings with energy indicators using data on construction periods of buildings, showing the heat density per street. As the Climate Protection Framework Concept only considers the period up to 2030, it recommends developing a heating concept for 2050 as increased energy-efficient refurbishment of buildings is expected from 2030 onwards from the housing associations. (B.A.U.M. Consult, 2015)

In the BMU-funded climate protection sub-concept “CO2-free Heat Supply 4.0”, it was analysed how a CO2-free heat supply can be reached in 2050 (Cobios Consult, undated). For the future heat demand, different scenarios are developed, and for the future of the DH grid, engineering firms working on the topic asked about necessary technical adjustments in the future. According to them, lowering the temperature of the DH is sensible, and that the DH grid has immense potential for optimisation. (Interview 4)

Asked about long-term goals to lower the temperature of the DH grid, the practitioner from the DH operator states that there are currently no goals to lower the temperature beyond 2022 and that the topic will be considered sometime in the future (Interview 3).

Tactical Transition Management

In the climate protection sub-concept “CO2-free Heat Supply 4.0”, a roadmap was created on how to reach a CO2-neutral heat supply in 2050 (Cobios Consult, undated). The roadmap shows that lowering the temperature should be understood as a continuously undertaken process, taking the whole system into account. The concept further indicates that making the DH supply climate-neutral is faster than waiting for the energy-efficient refurbishment of buildings that is expected after 2025. (Interview 4)
The built biomass CHP plants have legally guaranteed payment for the electricity around 2030, providing the base load for the DH grid and limiting the potential for expansion to the middle load (B.A.U.M. Consult, 2015; Interview 3).

For implementing the Climate Protection Framework Concept, a Climate Competence Centre located at an external company, called Cobios Consult GmbH, was founded in 2015 and financed by the city (Interview 4). The Climate Competence Centre should coordinate, document, and develop the Climate Protection Framework Concept further and was the central contact for energy consulting (B.A.U.M. Consult, 2015; Interview 4). The idea was that an external climate protection manager has more time for the tasks as the need for documentation is much smaller compared to a funded climate protection manager, and the relationship between the city and the independent climate protection manager is different. However, the City Council decided to terminate the contract with Cobios Consult, working only together on specific projects now. Cobios Consult is not involved in the process of transitioning the DH grid anymore. (Interview 4)
The City Council decided that a sustainability manager is to be employed in the municipal administration (Henningsdorf City Council, 2020b). The sustainability manager started working at the beginning of June and will be involved in the necessary coordination of climate protection projects between the city of Henningsdorf and SWH (Interview 3).

There is a legal obligation to connect to and use the public DH grid (City of Henningsdorf, 2007).

In the mid-1990s, the TABs were changed, reducing the requirements for the RT to 50°C. Substations installed and heating systems connected since then need to be designed for this RT level. (Interview 3)

Since the beginning of the 1990s, SWH offers heating as a service, installing, operating, and maintaining the substation. Around 80% of the substations are owned and operated by SWH. Most of the radiators in the buildings are designed for ST of 90°C and RT of 70°C. The radiators are generally oversized as design programmes include an area reserve, making it possible to use lower temperatures. The area reserve and the operation of the substations enable SWH to operate the heating systems in the buildings with lower temperatures than the design temperatures. (Interview 3)

Decentral solar thermal heat from customers is to be implemented into the DH grid, converting heat customers into heat prosumers (SWH, 2019)

Operational Transition Management

In the second phase of the project “Heating Hub”, a buffer heat storage with 1,000 m³, multi-purpose heat storage with 22,000 m³, providing daily to seasonal heat storage, and an open space solar thermal facility of 3,000 m³ are to be constructed (Interview 3; SWH, 2019). Furthermore, excess heat from the local steel plant and decentral solar thermal heat from customers are to be integrated into the DH grid (SWH, 2019). To better integrate decentralised, discontinuous renewable and excess heat sources, sensors, measuring the ST and RTs and the pressure, and control technology will be implemented in the DH grid and at heat production facilities (Interview 3).

To reduce the heat losses in the grid and enable the usage of heat storage without pressure and, thus, far more cost-efficient, the ST in the DH grid shall be reduced to 95 °C (Interview 3; SWH & Ruppin Consult, 2017). For lowering the ST in the buildings, data on the heating system installed in the building will be collected this year (Interview 3). For this, heating installers will conduct as part of the yearly maintenance, site visits at all connected buildings to see where the temperature limit of reducing the temperature in the heating system lies, if the heating systems are balanced correctly, and adjust the operation of the substations accordingly. The heating installers of SWH will conduct these visits with the support of an engineering company to integrate the procedure in the everyday work of operating and maintaining the substations of the customers. (Interview 3)

The substations are currently replaced as part of the regular renewal cycle of over 20 years with smart substations that can measure the heat demand, ST, and RT and can be controlled remotely (Interview 3).

Reflexive Transition Management

The experiences show that converting DH to an 80% climate-neutral heat supply requires enormous investments. The project “Heating Hub” has investment costs of 16 million €, and the biomass and biomethane CHP power plants investment costs of 20 million €. These high investments are refinanced through heat sales, resulting in price increases of 13% for the customers. This price increase has led to discontent and debates about the socially acceptable price level of heating. The practitioner from SWH states that it is essential to discuss the options and communicate the benefits of low-carbon DH and also the resulting future prices transparently and understandably from the beginning. (Interview 3)

Former analyses show that Geothermal is usable. However, the high investment costs and the high risk of these investments have eliminated this option for SWH so far. In the WindNODE project, the prerequisites for building and operating the electrode boiler regarding space and hydraulic conditions were created and buffer storage was constructed. However, as all tariffs on the electricity price even for excess electricity have to be paid, the operation of the electrode boilers is uneconomic compared to natural gas and the boiler has not been built yet. (Interview 3).

Regarding the involvement of actors in the process, the practitioner from SWH states that reaching the broad mass of actors is extremely difficult. Stakeholder meetings mostly reach the people that are already on board, like energy providers, urban planners responsible for city development, and societal initiatives for climate protection, but not the broad mass. (Interview 3)

In the climate protection sub-concept “CO2-free Heat Supply 4.0”, a controlling strategy was drawn up on how a CO2-neutral heat supply can be reached in 2050 (Cobios Consult, undated). Asked about the sub-concept, the interviewee from the DH operator said that the focus was on applying scientific methods to analyse potential pathways and the concept is rather theoretical (Interview 3).

The City Council discussed evaluating the Climate Protection Framework Concept or applying for funding to develop a new climate protection concept for the city, serving as a strategic basis and planning aid for decision-making and anchoring climate protection in the municipal administration (Henningsdorf City Council, 2020a). As Henningsdorf will not receive funding to implement the existing Climate Protection Framework Concept or develop a new climate protection concept, the City Council decided to develop a sustainability strategy (Henningsdorf City Council, 2020b).

For the transition, the practitioner from SWH expressed the importance of funding for technologies as they lack the economic viability compared to established fossil fuel technologies and the importance of having reliable regulative framework conditions for investment decisions (Interview 3).

Analyses show that excess heat from the local industry at around 60 °C is available. With the current framework conditions, however, using this excess heat is not economical. The practitioner from the Climate Competence Centre states that as economic framework conditions can change, it is crucial to make it technically possible and more efficient to use these heat sources by lowering the temperature of the DH grid. (Interview 4)

The practitioner from the Climate Competence Centre states that with the current speed of the transition and the complex political framework that favour the current status quo, the goal of a climate-neutral heat supply by 2050 will not be reached. According to the practitioner, the transition speed is linked to the available, often limited financial and personnel resources. For example, there is a lack of energy consultants analysing and craftsmen implementing energy-efficient refurbishment measures. A central part of the daily work is to convince people that climate protection is essential and should be undertaken even if it might cost more. According to the practitioner, a radical political transition to speed up the process and develop supportive framework conditions, motivating people to develop climate protection solutions together, is necessary. (Interview 4)

Appendix D: Case Study Jena

Strategic Transition Management

The Sustainability Strategy was developed by a steering group consisting of the six topic mentors in the administration with participation from representatives from civil society, local businesses, and politics (City of Jena, 2020; Interview 6). During the strategy development, information exchange on topics, goals, and possible measures took place with the six municipalities, which also participated in the project "Global Sustainable Municipality Thuringia" funded by the Federal Ministry for Economic Cooperation and Development (Interview 6; Zukunftsfähiges Thüringen, undated). The City Council adopted the Sustainability Strategy in 2021, thereby adopting the goal to reduce the GHG emissions by 20 to 30% by 2030 compared to 2016 - which means a reduction by 84 to 91 % compared to 1990 levels (Zukunftsfähiges Thüringen, undated; ThINK, 2019). For the DH grid, a concept shall be developed until 2025 showing how the energy demand, including electricity and heat, can be covered by at least 80%, preferably 100%, renewable sources by 2040. For the temperature of the DH grid, the aim is that until 2025 most of the customers and until 2030, the vast number of customers can be supplied with lower STs. (City of Jena, 2020)

In the BMU-funded project "Transformation Strategies DH", a transformation strategy to increase the share of renewable heat in the DH grid by 2030 and 2050 was developed by consultancies and SWJ (Paar et al., 2013; Schöttke et al., 2016). The results show that the high temperature level significantly hampers the integration of renewable heat in the DH grid. To integrate renewable heat better, also economically, the temperatures of the DH grid are to be lowered. (Paar et al., 2013)

In the BMWi-funded project "Integrated Energy and Heat Concept for Jena 2050", SWEJ developed an energy supply concept with consultancies and research organisations. The energy efficiency of buildings is assessed for districts with a similar building stock. For this, based on type and construction period reference buildings are developed. For the reference buildings, energy indicators are simulated based on generally used construction methods of wall structures, building materials, and thermal standards in the construction period. For these reference buildings, heating profiles are simulated showing the hourly heating demand. For the energy supply concept, three scenarios for the future energy demand, taking the economic development, demographic factors, and energy-efficiency of buildings into account, are simulated. One for the renovation rate that is seen as being most realistic for Jena with a linear decrease to 0.5% in 2025 as many old buildings are already partially renovated and a linear increase to 1% by 2050, one with the current rate of the refurbishment of around 1.25% gained by a representative survey for 2011 and one that is significantly higher with a linear increase to 2% by 2025 and a from 2025 to 2050 a linear increase to 3% for approximately reaching a climate-neutral building stock by 2050.

For these three scenarios, the effect on the DH grid was simulated, assessing if it is sensible to separate the DH grid into smaller, individual DH grids or not. The results show that a central DH grid is more flexible regarding heat generation than smaller, individual grids and should be maintained for the time being. Due to heat demand reduction, the option of separate grids could become sensible in the future and should be examined at a later stage again. Simulations of the central DH grid show that free transport capacities due to the energy-efficient refurbishment of buildings are available, making it possible to lower the DH grid's ST, connect new customers, or both (Interview 7; Schöttke et al., 2016). In the district Lobeda-West, tests to lower the ST, first from 130 to 120 °C and then to 115 °C, were carried out, and the effect on the DH grid and the customers was monitored. Based on the results, the ST will be decreased permanently. The DH grid is to be analysed to assess if it is possible to reduce the STs in other parts of the DH grid. The report further concludes that temperature reductions by lowering the RT should be pursued in the future. (Schöttke et al., 2016)

For expanding the DH grid, the expansion potential for 32 districts is currently assessed (Interview 5).

For the geothermal potential, a geological survey of the entire city area has been developed, and based on this, the potential on a specific site analysed. For solar thermal and excess heat, the analysis of the potential is focused on particular sites, like using excess heat from the cleaned sewage water, and not available for the whole city area. (Interview 7)

SWEJ is currently developing the concept for reaching a nearly climate-neutral DH supply by 2040 as required by the Thuringia Climate Act. In the beginning, a meeting with the climate protection manager and a citizen energy cooperative to exchange ideas on what could be included in the concept was held (Interview 6). For the information exchange between the city administration and SWEJ, regular climate rounds are held, including the concept's state (Interview 6). Several Thuringia Stadtwerke formed a working group in the second half of 2020 to support and learn from each other and discuss the procedure to meet the requirements (Interview 7). Having said this, the practitioners from SWJ state that the development of the technical concept is strategically a topic of SWJ (Interview 5 & 7). Asked about if the concept will include the building side, the practitioners from SWJ state that the necessary data basis is not available and that statements on the energy-efficient refurbishment of buildings could only be made for buildings owned by SWJ (Interview 5 & 7).

Future temperature levels of the DH grid were identified based on tests and simulations (Interview 5 & 7). In Jena, the future temperature levels of the DH grids in Jena are 40°C for the RT, and 70-90°C, 75-90°C, and 80-115°C for the ST of the DH grids with STs of over 90°C and remain by 60-90°C for the DH grid with maximal ST of 90°C (SWJ, 2019; Interview 7).

Tactical Transition Management

The concept currently developed will list measures on how to reach a nearly-climate neutral DH supply by 2040 (Thuringia Climate Act, 2018).

Municipalities in Thuringia can carry out heat analyses and heat concepts, preferably on the district level, estimating the heat demand and the renewable and excess heat sources available to cover them and deriving measures for reducing and meeting the heat demand. For this, the Thuringian

State Office for Statistics provides the necessary and available energy data. (Thuringia Climate Act, 2018)
Asked about developing these heat analyses and heat concepts, the practitioners state that they currently have no plans to create them at the district level (Interview 6 & 7).

The Consumer Centre Thuringia and SWEJ offer energy consulting services (Interview 6).

Until 2037 the Thüringer Energie AG (TEAG) will supply heat from the natural-gas fired CHP plant, supplying around 98% of the heat in 2015 (Interview 5; Schöttke et al., 2016).

There is a legal obligation to connect to and use the public DH grid (City of Jena, 2019).

In 2019, the TABs were adapted, including the goals of the future temperature levels, reducing the requirements for the RT from maximal 55 to maximal 40°C (SWJ, 2019). The STs listed in the TABs are the goals of the future STs, including a reduction of the ST in winter and in some cases in winter and summer (Interview 7; SWJ, 2019). For the DH grids with STs of over 90°C in winter, the design parameters for the STs are reduced from 70-105°C to 70-90°C, 75-110 to 75-90 °C, from 80-130°C to 80-115°C, and from 95-130 to 80-115 °C (SWJ, 2019). For the DH grid with a maximum ST of 90°C, the ST written in the TAB remain by 60-90°C (SWJ, 2019). By changing the temperature levels in the TABs, new substations are built for and substations that need to be modernised adapted to lower temperature levels as part of a regular renewal cycle (Schöttke et al., 2016; Interview 7). According to the TABs, the new RT of 40°C applies to existing customers ten years after adapting the TABs (SWJ, 2019).
The TABs prescribe that the heating system in the building that is to be connected to the DH grid has to be hydraulically balanced and that a flow limiter is to be implemented (SWJ, 2019). The maximum flow rates passing through the flow limiter are calculated based on the reported maximum load capacity and the differences between maximal ST and maximal RT (SWJ, 2019). The basic price depends on the maximum load capacity written in the contract (SWJ, undated).

At specific grid nodes and larger customers, STs and RTs are measured remotely (Interview 5; Schöttke et al., 2016). For large customers, higher RTs than agreed in the contract are penalised and measures discussed with the customer and for further planning of the measures, refer customers to planning offices (Interview 5 & 7). In the future, price calculations shall be developed to incentivise lower RTs and the existing malus refined to be more effective (Interview 5 & 7).

SWEJ offers, together with two subsidiaries, a heating service to install, operate and maintain the substation of the customer for a capacity of over 30 kW (SWEJ, undated b). Around 40% of the substations are owned, operated, and maintained by the subsidies (Interview 7).

Operational Transition Management

The heat meters are currently replaced as part of the regular renewal with heat meters that can measure the heat demand, ST, and RTs of the customers remotely (Interview 7).

As simulations show that free transport capacities are available in the DH grid, tests will be carried out in the heating period 2021 to lower the ST of the primary grid by ten °C to identify weak points or possible supply bottlenecks (Interview 7).
Depending on the heat demand of the new customers in the 32 districts and if these districts are connected to the existing DH grid, the free transport capacities in the DH grid and the possibility to lower the STs might be affected (Interview 5 & 7).

The TEAG has recently constructed a 63 MW gas engine, generating electricity and heat for the DH grid, and around 8,800 m³ heat storages designed for temperatures of up to 144°C (TEAG, undated).

Reflexive Transition Management

Regarding the involvement of actors in the process, the practitioner from SWJN states that communicating with involved actors, including the customers, the municipality, and the TEAG, is crucial (Interview 7). For lowering the temperatures, the practitioner from the SWEJ states that it is important to communicate with the customers and reassure them that the security of supply is also given with lower temperatures and to create pressure to act by implementing the bonus-malus tariff system (Interview 5).

The practitioner from the SWJN states that the available area for using renewable heat in the city and for the excess heat from the sewage treatment plant is very limited (Interview 7).

The Sustainability Strategy shall be monitored and evaluated every two years (Interview 6). For implementing and monitoring the Sustainability Strategy, as opposed to the development, there is only an information exchange with Erfurt (Interview 6). According to the Sustainability Strategy, every five years, the concept of reaching 80%, preferably 100% renewable energy supply by 2040, will be evaluated based on legal and technical feasibility (City of Jena, 2020).

The Integrated Energy and Climate Protection Concept shows that from an economic perspective natural gas is the most favourable DH generation for the relevant order of magnitude (Schöttke et al., 2016). For the transition of the DH grid, the practitioner from SWEJ states that better political framework conditions, especially regarding economics, need to be developed using the knowledge and experiences from the practice (Interview 5). The current funding programmes from BAFA, for example, provide funding for installing heating systems but cannot be used to connect buildings to the DH grid (Interview 5). For gaining funding for the connection, the DH grid needs to be supplied by at least 25% (BAFA, 2021a). The practitioner from SWJN states that the support programme for the transition of existing DH grids needs to be made relatively easy to handle (Interview 7).

Appendix E: Case Study Potsdam

Strategic Transition Management

In 2012, the City Council decided that from 2050 onwards, EWP should supply Potsdam only with renewable energies (City of Potsdam et al., 2013). In 2019, the City Council declared climate emergency, acknowledging that consistent and rapid implementation of the Master Plan 100% Climate Protection and additional efforts are necessary to reach the goal of reducing the GHG emissions to 0.3 t CO_2 equivalent per inhabitant and year - which means a reduction by 95 % compared to 1990 levels (Lange et al., 2017a; Potsdam City Council, 2019).

The Master Plan was created by a consortium of research and consulting institutions with the participation of the Climate Protection Department and the Potsdam Climate Council. The Potsdam Climate Council consists of 20 experts and decision-makers advising the mayor on climate protection and climate adaptation topics. In the Master Plan 100% Climate Protection, a vision for a climate-neutral Potsdam has been developed, seeing climate protection as a joint, innovative, urban transformation fostering sustainable urban and regional development. For the heat demand, a city model was developed combining existing (spatial) data sets on the location of buildings, historic preservation, number of storeys, gas and DH consumption on street level from SWP, and number of central firing places to make statements about the district and city level. As Potsdam is a growing city and 53 % of the gross floor area in Potsdam is under historic preservation, halving the energy demand seems not possible, and a reduction of 35% is set as a goal in the Master Plan 100% Climate Protection. For reaching this goal, the renovation rate needs to be 2% on average and for the renovation depth and new houses an energy efficiency standard of at least KfW 55. For increasing the renovation rate, technical restrictions due to historic preservation and the social acceptance due to increasing rents are listed as key obstacles. The heat demand covered by DH is projected to be on the same level as today owing to the increase of the connection rate, the expansion of the existing DH grid, and the development of new, smaller DH grids. (Lange et al., 2017a)

As part of developing the Master Plan 100% Climate Protection, sub-studies on reaching a climate-neutral DH grid by 2050, and on the potential of using geothermal and excess heat from the river are developed. For assessing the potential of solar thermal, data from the solar potential register has been used. (Lange et al., 2017a)

In the future, the heat generation portfolio is envisioned to change significantly. Heat storage will enable the CHP plant and the electrode boiler to be operated according to the electricity market, providing flexibility to integrate fluctuating renewable electricity. Furthermore, solar thermal, geothermal, and environmental heat using heat pumps to increase the temperature are seen as future DH sources. (Lange et al., 2017b)

In the Master Plan 100% Climate Protection and the Action Programmes, the district level is emphasised as the essential planning level for the energy supply of buildings (City of Potsdam, 2018; Lange et al., 2017a; Potsdam City Council, 2020b). For the districts Krampnitz and Drewitz, concepts were developed and for the district Schlaatz, concepts are currently being developed (Interview 9). The former barracks complex Krampnitz will be converted into a new residential district, providing housing for around 10,000 citizens (City of Potsdam, 2021c). For this, concepts on mobility, social and cultural infrastructure, supply and disposal infrastructure were developed

(City of Potsdam, 2021c). For the energy supply, an energy concept was developed targeting a fossil-free energy supply by 2040/50 (EWP, 2018). A new DH grid with a ST of 50°C and a RT of 30°C is to be developed using renewable heat sources (Potsdam City Council, 2020a). For the district Drewitz, the integrated energy and climate protection concept commissioned by the city of Potsdam, the municipal housing association ProPotsdam and EWP shows how the GHG emissions can be reduced by over 80% by 2050 (City of Potsdam et al., 2013). The concept encompasses the action fields energy-efficient refurbishment of buildings, optimisation of the heat supply, renewable energies, mobility, and the adaptation to climate change (City of Potsdam et al., 2013). Experiences from the implementation of the concept and the redevelopment management in Drewitz show that the participation of the local citizens needs to be improved in some way (Interview 9). For the district Schlaatz, energy, climate protection, and mobility concepts are currently being developed commissioned by EWP and the alliance between the municipality and the housing associations, including how the temperature of the DH grid can be lowered (Interview 9). The experiences from Drewitz also showed that the local citizens are not that interested in the energy topic, beyond that the home has to be warm and the electricity has to be available, and that the citizens need to be involved better in the process (Interview 9). Therefore, in Schlaatz, greater emphasis is placed on public relations and participation of the local citizens already in the development of the concepts (Interview 9). For addressing the local citizens better, visions for a sustainable Schlaatz in 2030 are developed together with citizens, including various aspects, like climate protection, community, green spaces, mobility, participation, social life, and quality of living (Interview 9; Schwarz, 2019).

An energy utilisation plan will be developed, mapping the energy demand, existing heating supply infrastructure, and potential energy supply sources, to assist the development of energy concepts at district level (City of Potsdam, 2018; Interview 9). The energy utilisation plan will spatially map the current energy demand and the future energy demand based on the Master Plan 100% Climate Protection scenarios (Interview 9). For the energy supply, the energy utilisation plan will spatially map the potential of shallow and deep geothermal, biomass, wind, solar thermal, photovoltaic, and excess heat, including commercial, data centres, and wastewater (Interview 9).

To better integrate renewable heat sources, using one-stage instead of two-stage heat pump systems, and reduce the heat losses, the temperatures of the DH grid shall be lowered (Lange et al., 2017b).

For determining future temperature levels of the DH grid, different temperature levels were modelled, comparing

- the security of supply - among other things the legionella prevention, reserves to cover heat demand,
- the economy - among other things, the investment costs,
- and the ecology - among other things, heat losses and type of heat pump (Interview 8).

Based on these results, the targets for the future temperature levels by 2050 with RT of 30°C and ST of 80°C in the primary and 50°C in the secondary DH grids are decided (Interview 8; SWP, 2020).

Tactical Transition Management

The City Council adopted the core strategies of the Master Plan 100% Climate Protection as a regulatory framework for future policy and adopted the Action Programme, listing short-, middle- and long-term measures that shall be implemented (City of Potsdam, 2018; Potsdam City Council, 2018a). For the DH grid, the sub-study “Climate-neutral DH” sets the pathway for transforming the DH grid by first reducing the RT and then the STs, first in individual parts of the DH grid and then in the entire DH grid, lowering the temperature levels written in the TABs and developing incentive systems (Interview 8; Lange et al., 2017b).

The Master Plan 100% Climate Protection states that the city should be divided into climate districts (Lange et al., 2017a). To assist the identification of districts and the development of energy concepts at the district level and secure areas for the construction of energy generation facilities using existing urban planning instruments, the energy utilisation plan is to be anchored as a new planning tool in the urban planning process (City of Potsdam, 2018; Interview 9; Potsdam City Council, 2020b).

For coordinating the implementation of the concepts, redevelopment managers are to be employed, and the Arbeitskreis StadtSpuren is involved in the process (Interview 9). The Arbeitskreis StadtSpuren, a working group to improve the quality of living consisting of the ProPotsdam, the Studentenwerk Potsdam, and seven housing associations, functions as a coordinator between its members (Interview 9; Arbeitskreis StadtSpuren, undated).

The first climate districts Krampnitz, Drewitz, and Schlaatz are identified as other urban redevelopment processes are already underway in the districts (Interview 9). For each of the three climate districts, cooperation between the Stadtwerke and the housing association(s) is set up. In Krampnitz, to split the risks of the high investment costs of implementing a fossil-free energy supply, a partnership agreement between EWP, SWP, and the housing association Deutsche Wohnen has been concluded (Interview 8). In Drewitz, a cooperation between the municipal housing association ProPotsdam and housing associations to jointly increase the energy-efficiency of the buildings and collaborative cooperation of ProPotsam, SWP, and the municipality are set up (Interview 9; Potsdam City Council, 2018b). Due to the positive experiences in Drewitz with the cooperation, aims to increase the collaboration shall be undertaken (Potsdam City Council, 2018b). For the district Schlaatz, an alliance between the municipality and the housing associations, providing around 85% of the district’s flats, is set up (Bündnis am Schlaatz, 2019; Interview 9). In Schlaatz, the collaboration between the city, the housing associations, and EWP is more intense, having a continuous contact person in the working group from the Stadtwerke (Interview 9).

The Consumer Centre Brandenburg and the Climate Agency of SWP offer energy consulting services (Interview 9).

The municipal housing association ProPotsdam takes a pioneering role, deciding to build new houses and renovate buildings 30% better than the energy-efficient standard requires (ProPotsdam, undated).

There is a legal obligation to connect to and use the DH grid (Lange et al., 2017b).

The TABs were updated in 2020, reducing the requirements for the RT to maximal 30 °C and including the future STs of the DH grids, as seen in Table 6 (Interview 8; SWP, 2020).

Table 6: Future supply and return temperature of the DH grids, Data Source: SWP (2020)

	2020		2025		2030		2035		2040		2045		2050	
	ST	RT	ST	RT	ST	RT	ST	RT	ST	RT	ST	RT	ST	RT
Primary Grid [°C]	125	55	118	55	110	50	103	45	95	40	88	35	80	30
Secondary Grids [°C]	80	50	79	50	73	47	68	43	62	38	56	34	50	30

As written in the Problem Area, all heating systems installed in the buildings must be able to use this ST (Leoni et al., 2020). Depending on the SH systems installed and the ST, energy-efficient refurbishment and hydraulically balancing the heat distribution, installing larger or additional radiators, or using individual heat pumps to increase the temperature might be necessary (Dalla Rosa et al., 2014; Averfalk et al., 2017). To avoid the risk of legionella, STs of 50°C require specific treatment methods or technologies for DHW preparation (Averfalk et al., 2017). By adopting the TABs now and publishing the future STs, new substations are built and existing substations replaced as part of the regular renewal cycle of 25 years with these future design parameters. By publishing the future, intermediate STs the building owners are informed and can integrate adopting their building(s) to lower STs in their investment decisions on building modernisation measures. By 2050, so the idea, only 5 to 10% of the substations need to be replaced. (Interview 8)

The TABs prescribe that volume flow controllers are to be implemented, limiting the volume flow based on the maximum load capacity and RT agreed in the contract (SWP, 2020). The basic price depends on the maximum load capacity written in the contract (SWP, 2021).

For ensuring that the new substations are implemented correctly and heating systems are hydraulically balanced correctly, EWP offers technical support, conducts training at guilds and housing associations regularly, and checks the schematic diagram of the substation (Interview 8).

When all substations are equipped with smart heat meters, a bonus-malus price system will be implemented to incentivise lower and penalise higher RTs (Interview 8).

Operational Transition Management

In Krampnitz, the development of a new DH grid having a ST of 50°C and a RT of 30°C is currently ongoing (Potsdam City Council, 2020a). Test drillings to investigate the potential of geothermal energy are approved and will be conducted (City of Potsdam, 2021c). In Drewitz, most of the

buildings have been renovated to the KfW 70 standard[9] (Interview 9). The energy-efficient refurbishment is still ongoing for the remaining buildings without the redevelopment manager coordinated by the Arbeitskreis StadtSpuren between the housing associations (Interview 9).
For Schlaatz, an energy-efficient urban redevelopment concept is currently being developed, including how the temperature of the DH grid can be lowered (Interview 9). For better integrating the local citizens in developing the concept, a new participation process is applied based on multi-stakeholder collaboration, experimenting, and continuously observing, evaluating, and analysing the process, developing sustainable visions together with citizens (Interview 9; Schwarz, 2019).

For three years, as part of the regular renewal, heat meters that reach their calibration deadline are replaced with heat meters to measure the heat demand, ST, and RTs of the customer remotely. In addition to the heating bill, customers with smart heat meters receive information on their RT, showing how many times they comply and do not comply with the RT specified in the contract. (Interview 8)

Reflexive Transition Management

Regarding the involvement of actors in the process, the experiences from the DH operator are that the implementation is challenging, requiring much effort to explain the reasons and involve the heating installers and technicians actively, and eventually, the customers, in the process. For this, it is essential to demonstrate that the implementation is possible - as will be done in Krampnitz for a new construction area (Potsdam City Council, 2020a) - and find appropriate ways to approach and reach out to people more. As the pure information send out on the RT does not provide an adequate incentive to reduce the RT for all customers, a bonus-malus price system is to be implemented. In a strategy workshop, the idea to accompany the customer as a service provider, also including the customer`s heating system, came up. (Interview 8)

The experiences gained in the districts shall be used for similar projects in the city (Potsdam City Council, 2020b). Whit the new DH grid developed in Krampnitz, initial experiences will be gained for the same ST and RT as the target temperature of the secondary DH grid (Potsdam City Council, 2020a). These experiences are to be used in the process of lowering the temperature of the existing DH grids (Potsdam City Council, 2020a). As a lesson learned from Drewitz, greater emphasis is placed on public relations and participation of the local citizens already in developing the concepts in Drewitz (Interview 9).

The Master Plan 100% Climate Protection should be evaluated every six years and every two years an Action Programme stating the short-, medium- and long-term measures developed (City of Potsdam, 2018; Interview 9; Potsdam City Council, 2018a). For the Action Programme, a progress report is written at the end on the measures listed in the Action Programme (Potsdam City Council, 2020c). The practitioner from the climate protection department states that evaluation is crucial

[9] The KfW 70 Standard requires buildings to have only 70% of the primary energy demand and 15% less transmission losses than the energy-efficient standard of the Building Energy Act requires (KfW, undated)

as it makes the process more tangible and transparent for politicians and citizens, informing about the measures taken and illustrating their effect, and enables to derive further measures and adjust the process. Having said this, the practitioner states that with the limited personnel resources, the focus is currently more on the implementation than on the evaluation, using the Master Plan 100% Climate Protection as a guideline. For the energy utilisation plan, the aim is to update the data in cooperation with SWP continuously. (Interview 9)

The heating costs will increase as even with funding, renewable heating technologies are more expensive than fossil fuels, and the costs for planning and implementing will also be included in the prices. For the transition, the practitioners from EWP state that increasing the funding is essential. (Interview 8)

For the transition, the practitioner from the climate protection department states that more personnel resources and clear framework conditions and requirements to reach the goal of climate neutrality are necessary. For example, the requirements for new buildings set in the Building Energy Act are insufficient to reach the set goals. Due to the lack of an adequate legal framework, the municipal goals to reach 95% GHG emission reduction and 100% renewable energy supply must be incorporated individually in every construction project, being very time-consuming and personnel-intensive. Also, for providing a relevant incentive, the practitioner emphasises that the CO2 price in regards to who is paying it and that more qualified craftsmen than available today are necessary. Asked about cooperation with and training the local craftsmen, the practitioner says that according to the guild asked during the development of the Master Plan 100% Climate Protection, the craftsmen are not that interested in training due to the excellent order situation. Also, the business development, the responsible department in the municipality, has not offered any training in this regard yet. (Interview 9)

Appendix F: Case Study Rostock

Strategic Transition Management

In 2020, the City Council decided that Rostock should become climate-neutral by 2035. The city administration and municipal companies should take a pioneering role, reducing GHG emissions by 95% by 2030 compared to 2019. (Rostock City Council, 2020a)

The Master Plan 100% Climate Protection from the year 2014 analyses how a 95% reduction of GHG emissions and a 50% energy demand reduction both compared to 1990 levels can be reached (City of Rostock & GICON, 2014). For the development of the Master Plan 100% Climate Protection, no analyses for the future development of the existing DH grid are conducted. The perception of climate change has changed significantly, from explaining the reasons for undertaking measures on climate protection to why measures are not implemented faster. In the BMU-funded project "Climate Protection in Public Projects", the heat supply for a new development area with single-family houses on the city's outskirts was analysed. Within the project, it became clear that heat supply plays almost no role in planning new development areas. To act strategically in developing a 100% fossil-free heat supply, a funding application was submitted in 2018, and currently, the "Heat Plan 2050" is being developed. Due to the City Council's resolution to become climate-neutral by 2035, the timeframe of the Heat Plan has been changed to 2035, meaning that the plan must be implemented faster. (Interview 10)

SWR as operator of the DH, electricity, gas, and broadband grid has developed a future vision for these grids (Schubert, 2020; SWR, undated). In the future energy system, the electricity grid delivers electricity from renewable sources, the DH grid heat from climate-neutral heat sources, and the gas grid climate-neutral gases. These three grids are coupled with the broadband grid using ICT. The DH grid will provide flexibility for integrating fluctuating renewables in the electricity grid using heat storage, CHP, and Power-to-heat plants. In the project "Hy Rostock Hydrogen Region", an electrolyser plant is planned to be constructed coupling the three grids by converting electricity into hydrogen and using the excess heat in the DH grid. (Schubert, 2020)

The project group developing the Heat Plan 2035 consists of

- employees from SWR,
- employees from the climate protection department, the environmental planning department, and the urban planning department of the municipality,
- two representatives from the local politics,
- an employee from the University of Rostock from the Chair of Technical Thermodynamics to use the local know-how on energy system modelling,
- the managing director of the State Association of North German Housing Companies as a spokesperson for the housing associations representing the customer side,
- one representative from the working group Energy Transition of the Agenda 21 committee for the expert know-how and to integrate engaged citizens,
- external experts,
- and a general coordinator. (Interview 10; Zander & Hempfling, 2020)

For the development of the Heat Plan, several working groups were developed (Interview 10). These working groups will develop ten export reports on the topics Heat demand & energy efficiency of buildings, Development of the DH grid, Large-scale heat storage, Energy system modelling, Financing and Biomass, Excess heat & excess cold, Geothermal, Large-scale heat pump, and Solar thermal as heat sources. (Zander & Hempfling, 2020; Zander, 2021)

For the heat demand, data on DH and gas consumption from SWR is analysed at the district level. For the energy efficiency of buildings, the housing associations are asked by the general coordinator to provide data on the energy efficiency standard of their buildings. For the privately-owned buildings, the approximate age of the building is known. The working group for the topic DH grid development meets weekly, discusses, and develops ideas on the expansion of the DH grid, the integration and storage of renewable and excess heat, and the reduction of the temperature of the DH grid (Interview 10; Zander, 2021). For analysing the potential and economics of the heat sources, the temperature level of the DH grid in summer, meaning 85 °C, is used. For the potential of excess heat, the amount, temperature level, and timely availability of the heat sources will be

assessed. For biomass, the local and regional is assessed (Zander & Hempfling, 2020). The results of the individual working groups will be combined in the energy system model, modelling the heat demand and the heat sources available to cover this demand hourly to ensure the security of supply. Primarily results show that reducing the heat demand is crucial to meet the heat demand, especially the peak demand. (Interview 10)
A heat map spatially mapping the heat demand, heat supply infrastructure, and potential heat sources will be developed (Interview 10; Zander & Hempfling, 2020).

Energy-efficient urban redevelopment concepts are to be developed (Rostock City Council, 2020b). The practitioner from the climate protection department states that for districts with a lot of old, not modernised buildings or buildings with historic facades, the focus will be more on the energy-efficient refurbishment of the buildings. For other districts, to generate synergies, the focus will include other aspects for which the KfW provides funding, like renewing the water supply and expanding the broadband grid. (Interview 10)

In the future, according to the practitioner from SWR, the temperature levels of the DH grid should be well below 100 °C to better integrate renewable and excess heat sources and large heat storage. For developing a transition plan, the hydraulic conditions of the DH grid and the substations and the potential to lower the temperatures need to be analysed. As a pilot project, analysis to lower the temperature of a district will be conducted. (Interview 11)

Tactical Transition Management

A plan listing concrete measures for the years 2022 to at least 2024 and rough measures for 2025 to 2035 shall be developed on how the municipal administration and companies can reduce their GHG emissions by 95% by 2030, reach climate neutrality by 2035 and achieve a further reduction of compensation payments in favour of actual CO2 savings. (Rostock City Council, 2020a).
The Heat Plan aims to develop a milestone plan, showing how a fossil-free heat supply can be reached. In the Heat Plan, districts for which energy-efficient urban redevelopment concepts are to be created are selected based on the heat demand density and the willingness of the housing associations to participate. For the energy-efficient urban redevelopment concepts, redevelopment managers are to be employed to approach and involve the local actors in the process. (Interview 10)
The finished Heat Plan will be presented to the public and to the City Council in autumn 2021 to have a decision of the City Council to implement the plan (City of Rostock, undated). In addition to the City Council's decision, clear responsibilities shall be assigned and areas for the heating facilities secured in the land use plan to establish liability for the implementation (Zander & Hempfling, 2020).

This summer, an internal working group at SWR for the overall transition of the DH grid will be established (Interview 11). This working group will develop a transition plan to lower the temperatures of the existing DH grids, first for one district as a pilot project and, eventually, for the whole DH grid (Interview 11). The district for which the temperature of the DH grid is to be lowered was identified based on hydraulic conditions (Zander, 2021).

The Consumer Centre Mecklenburg-Western Pomerania and SWR offer energy consulting services (Interview 10).

There is a legal obligation to connect to and use the DH grid (City of Rostock, 2021c).

The TABs prescribe that flow limiters are to be implemented (SWR, 2020c). The maximum flow rates passing through the flow limiters are calculated based on the reported maximum load capacity and the in the contract agreed cooling of the RT (SWR, 2020c). The requirements for the RT are 50°C for heating systems, 35°C for ventilation and air-conditioning systems, 30°C for instantaneous heat exchanger and 40°C for DHW storage units (SWR, 2020c). The requirements for the individual customers result from the information on the type and capacity of the installed systems (Interview 11). When connecting buildings to the DH grid, SWR highlights the need to hydraulically balance the heating systems (Interview 11). For the correct implementation of the substations, the substation manufacturer trained the local heating installers (Interview 11).

At specific grid nodes, the STs and RTs are measured and reported continuously to the control centre. For the annual billing, the amount of heat delivered and RTs of the customers are read out using radio technology. (Interview 11)
The basic price of the DH tariff depends on the RTs and the reported capacity of the substation, incentivizing RT below 45 °C and penalizing RT over 60°C (SWR, 2021). For the capacity of the substation, the charged prices depend on the substation capacity used to calculate the maximum flow rates. If the heating system is not functioning correctly, the maximum flow rate needs to be increased to ensure thermal comfort, resulting in higher basic prices. (Interview 11)

SWR offer a heating service to install, operate and maintain the substation of the customers (SWR, undated). Around 40% of the substations are owned, operated, and maintained by SWR (Interview 11).

Operational Transition Management

Energy-efficient urban redevelopment concepts will be developed for the in the Heat Plan selected districts (Rostock City Council, 2020b).

The practitioner from SWR states that the possibility to gain funding from BAFA for developing the transition plan for the pilot district is to be examined and based on this a funding application is to be made (Interview 11).

SWR started to build a 20 MW electrode boiler and a 45,000 m³ heat storage designed for temperatures of up to 98°C (SWR, 2020b). For better usage of this heat storage, the temperatures of the DH grid shall be lowered in the future (Interview 11).

Reflexive Transition Management

For the development of the Heat Plan, the practitioners state that more time is necessary. The practitioner of SWR says that in the beginning, time is necessary to find a common language and develop a shared understanding of the topic (Interview 11). The practitioner from the climate protection department states that more time than anticipated, especially for writing the tenders and organising the process is necessary. The final Heat Plan will not describe the way to a climate-neutral heat supply in 2035 but only present an interim status, making further investigations on the district level and heat sources necessary. (Interview 10)
The experiences gained in the pilot district for lowering the temperature of the existing DH grid will be used in the other parts of the DH grid (Interview 11).
From the info questionnaire sent out to inform the citizens on the project and from speaking with people working in the municipal administration, the practitioner from the climate protection department says that the knowledge level on the heat transition is not that great. Experiences from developing the Heat Plan show that involving, communicating, and explaining more about the topic is essential to create a shared understanding. This understanding, so the practitioner from the climate protection department, helps motivate the actors to work on the transition actively. Including external experts in the process provides an additional viewpoint on the topic and can help convince people that this is the right way. Having said this, the development of the Heat Plan also revealed that there are actors who are not that interested in the topic. (Interview 10)

For monitoring the goal to reduce the GHG emissions by 95% compared to 2019, the city administration and municipal companies have to report the current status in a short overview annually and at least all three years more detailed on the development of their CO2 emissions, the use of renewable and fossil energies, energy savings, and planned measures for the coming three years. The municipal administration also has to include the development of the CO2 emissions for the whole city in the report. (Rostock City Council, 2020a)
A monitoring and controlling strategy will be developed for the Heat Plan to adjust the pathway on reaching a fossil-free heat supply (Zander & Hempfling, 2020). The idea is to continuously update the data in the heat map on the energy-efficient refurbishment of the buildings by coordinating with SWR and possibly by analysing data from funding programmes (Interview 10).

The first calculations show that the heat production costs of low-carbon heat sources are more expensive than using fossil fuels due to the low prices of fossil fuels and the maturity of the technology (Interview 11). In the case of heat pumps the prices for purchasing electricity include all tariffs and in the case of high-temperature heat pumps the technology is not even mature yet, making them uneconomic compared to fossil fuel technologies (Interview 11). In the Heat Plan, the idea came up to involve the citizens financially to fund concrete projects and concepts to increase their acceptance, enhance the public awareness and create greater solidarity (Interview 10 & 11).

For the transition of the DH grid, the practitioner from the climate protection department states that the legal framework conditions need to be stricter to reach the climate protection goals, like the building standards for new buildings (Interview 10). Furthermore, more personnel resources are necessary for writing tenders for funding programmes, coordinating the projects, and reporting (Interview 10). Regarding the availability of data, the practitioner states that there needs to be easier ways to gain the necessary data than to depend on the actors' willingness, by having, for example, an obligation to report the estimated heat demand for new construction areas (Interview 10).

Also, the practitioner from SWR states that the tasks of developing the transition plan of the DH grid are very extensive (Interview 11). Even if the analyses are outsourced, personnel at SWR must first write the tender and then be a contact person for the external company, providing them with data, for example (Interview 11).

For the heat transition, the practitioner from SWR states that ways should be found to bring everybody on board, also the tenants, so that all are willing to participate in developing climate-neutral heat solutions. According to the practitioner, it is necessary to solve the landlord-tenant dilemma and create pressure to act by setting legal requirements also for the existing building stock. (Interview 11)

Appendix G: Case Study Springe

Strategic Transition Management

The Climate Protection Action Programme that aims to reduce the GHG emissions to 2 t CO_2 equivalent per inhabitant, which means a reduction by around 76% compared to 2005 levels, recommends that the potential for developing small DH grids shall be analysed (City of Springe, 2010). For increasing the rate of the energy-efficient refurbishment of buildings, the climate protection concept lists, among others, the lack of financial resources, the complexity of the topic and the oversupply of information unsettling the building owners as obstacles (City of Springe, 2010).

As SWS was founded 13 years ago to re-municipalise the grids, much of the organisational work was outsourced to BS Energy. In 2016, the DH division of the BS Energy started to calculate if developing a DH grid would be economically feasible. The goal is to cover as much of the heat demand supplied by the DH grid with locally available renewable and excess heat sources. For the planning of the DH grid, the solar thermal, biogas, wood, and excess heat potential were analysed. The wood used in the heating and CHP plant comes and should come from surrounding forests. (Interview 12)

The three KfW-funded energy-efficient urban redevelopment concepts largely cover the areas in which the DH grid is to be constructed (Michalczyk & Schwitalski, 2019). The concepts were developed by the Climate Protection Agency of the Region Hannover, the DH planning department, and the managing director of SWS. The redevelopment manager was already employed during creating the concept to offer energy consultancy and provide the link between citizens, the municipality, SWS, and the Climate Protection Agency of the Region Hannover (Interview 12; Michalczyk & Schwitalski, 2019). As part of developing the energy-efficient urban redevelopment concepts, ideas with citizens were developed on how Springe should look like in 2030, including

community, living, mobility, and renewable energy (Climate Protection Agency of the Region Hannover, undated). Both the request and over 70% of the remaining costs for developing the concepts come from SWS. Due to this, the focus is clearly on the energy-efficient refurbishment of buildings and the DH grid. The Climate Protection Agency of the Region Hannover added a focus on photovoltaic. (Interview 12)
The heat demand and energy-efficient status of the buildings located in the areas were assessed using gas consumption data available from SWS, data obtained from energy consultancy offered by the redevelopment manager, and by conducting site visits and using energy indicators recorded for Hannover (Interview 12; SWS, Michalczyk & Schwitalski, 2019). Outside these districts, there are only rough estimates of the heating demand based on floor area and estimated building age. The results of the energy-efficient urban redevelopment concepts show that existing buildings should be renovated using the EnerPHit standard[10] to reduce the heat demand so far that the remaining heat demand can be covered with the locally available renewable and excess heat sources in the future. (Interview 12)

In the future, the temperature level of the DH grid shall be lowered to reduce the heat losses and prepare the integration of further renewable and excess heat (Climate Protection and Energy Agency of Lower Saxony, 2019). When the temperature of the DH grid has been lowered, the excess heat potential of the sewage system shall be analysed in greater detail (Interview 12).
The future temperature levels of the DH grid have not yet been determined. For lowering the temperatures, the customers that require high STs and have high return temperatures are to be identified and measures and strategies derived to lower the requirements of the ST and the RT. (Interview 12)

Tactical Transition Management

The strategy is to first connect as many buildings as possible to the DH grid and then gradually decrease the temperature of the grid. To lower the DH grid's temperatures, a strategy to reduce the RT will be developed, and existing funding programmes for energy-efficient refurbishment used to prepare buildings for lower STs. (Interview 12)
The energy-efficient urban redevelopment concepts will be presented to the City Council this summer with the aim of having a political decision to implement them (Interview 12).
The redevelopment manager was already employed during the creation of the concept to have more continuity for coordinating between the citizens, the municipality, SWS, and the Climate Protection Agency of the Region Hannover, offer energy consulting services and use the obtained data to develop the concept (Interview 12; Michalczyk & Schwitalski, 2019). Besides the redevelopment manager, SWS offers energy consulting services (SWS, undated d).

[10] The EnerPHit Standard requires the use of passive house components for energy-efficient refurbishment of existing buildings (Passive House Institute, 2016)

In Springe, there is no legal obligation to connect and use the planned DH grid. Based on experiences working as an energy consultant for 20 years, the practitioner states that many customers see DH tariffs critically due to their natural monopoly position. For this, according to the practitioner, it is good that DH has to compete with other heat sources, and for the competition that the CO2 tax makes gas and oil foreseeable more expensive in the future. (Interview 12)

The TABs prescribe to implement smart substations that can be controlled remotely to operate the substations and the DH grid more efficiently (Interview 12; SWS, 2017). The requirements for the RT are maximal 50°C for heating systems, 40°C for ventilation and air-conditioning systems, and 40°C for DHW preparation systems (SWS, 2017).

For implementing and maintaining the substations, the city insisted on cooperation between SWS and the local heating installers. In this cooperation, the local heating installers sell and maintain the substations of the customers. To ensure that the smart substation can be controlled from the central control system, SWS prescribed the manufacturer (Interview 12; SWS, 2017). For the correct implementation and maintenance of the substations, the substation manufacturer trained the local heating installers. (Interview 12)

Operational Transition Management

With the granted subsidy from Projektträger Jülich, the DH and broadband grid are currently being developed (Interview 12). With the broadband grid, the connection of the substations to the central control system is planned to operate the substations and the DH grid more efficiently and meter the heat demand, the ST and RT levels remotely (Interview 12; SWS, 2017). Shortly, SWS will develop an energy portal for customers, displaying their heat demand and associated CO2 emissions (Interview 12; SWS, undated c).
In the next heating season, the data from the smart substations will be used to identify customers with high RTs and to analyse patterns of heat consumption. For large customers, a control strategy for the smart substations is to be developed to shift or stretch their peak demand. (Interview 12)

The redevelopment manager states that an essential part of the work is advising the citizens about the existing funding programmes for connecting to the DH grid and the energy-efficient refurbishment of buildings (Interview 12).

Reflexive Transition Management

The practitioner states that the funding provided by the Projektträger Jülich for developing the DH and broadband grid is crucial for being able to compete with fossil fuels (Interview 12). For connecting new buildings to the DH grid, the requirements of the Building Energy Act make recruiting customers a lot easier (Interview 12). The Building Energy Act requires new buildings to have a specific yearly primary energy demand and either decrease the heat demand by an additional 15% or sourcing a minimum share of the heating demand from renewables (Building Energy Act, 2020). As the primary energy factor of the DH in Springe is only 0.3 - compared to natural gas and oil with 1.1 - and the obligation to heat a minimum share with renewables can be fulfilled by supplying the building with DH, DH is a very attractive heat source for new buildings (Interview 12; Building Energy Act, 2020). For connecting buildings to the DH grid and energy-efficient refurbishment of buildings, the practitioner states that the new federal funding programme offers very good funding conditions (Interview 12). BAFA subsidises individual renovation roadmaps for buildings with 80% of the consultancy fees (BAFA, undated). Individual renovation roadmaps for buildings analyse the current energetic state of the building and its components, like envelopes, ceilings, and floor, and the means and costs for reaching specific efficiency standards (Interview 12). The individual renovation roadmap enables making well-founded decisions even for refurbishing individual parts by having a long-term perspective (Interview 12). By creating this individual renovation roadmap, 5% more subsidies for energy-efficient refurbishment measures to optimise the heating system and implement renewable heating technologies can be gained (BAFA, 2021a & 2021b; Interview 12). The costs for the connection to the DH grid can be subsidised by 35% (40% with individual renovation roadmap), for buildings that were previously heated with oil even 45% (50% with individual renovation roadmap), as the DH grid is supplied by over 55% renewable heat (SWS, 2021; BAFA, 2021a). For reaching an efficiency house standard, due to the high share of renewables of around 77% and the low primary energy factor of the DH grid of 0.3, additional subsidies of 5% and 5-10% can be gained, respectively, as higher efficiency standards can be reached (Felsmann & Sander, 2018; Interview 12).

Regarding the cooperation with the local heating installers, the practitioner states that the cooperation is challenging as they are fixed on the technology that is well-known to them. Despite these challenges, the practitioner says that cooperation is very important. For addressing the people, the practitioner states that being present in the city and making personal contact is important and that the Covid 19 situation has significantly hampered this. (Interview 12)

The practitioner says that in most cases the time of a change of building ownership or modernisation measures is not known (Interview 12).

Asked about monitoring the energy-efficient refurbishment of buildings, the practitioner states that this is only possible for the buildings for which energy consultation was undertaken (Interview 12).

For the transition, the practitioner states that having reliable supportive framework conditions and more personnel resources is important. As an example, the practitioner states that the requirements for the insulation standard of new buildings are not sufficient to reach a climate-neutral heat supply and higher energy standards are economically feasible. For the three energy-efficient urban redevelopment concepts, only one redevelopment manager is employed and loaded with making energy consultancy, lectures, and public relations. Owing to the lack of personnel resources it is not possible to integrate other aspects, like mobility. (Interview 12)