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# Keeping the (Waste) Heat in the City

## Analyzing municipal governance of waste heat recovery in Turku, Gothenburg, and Rotterdam

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Thesis for the fulfilment of the
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# Abstract

The recovery of 'waste heat' from industrial and urban processes could meet a significant share of heating demands in urban and semi-urban areas. Replacing conventional heat sources in district heating (DH) systems with recovered heat could decrease primary energy inputs in a sector that globally relies to 90% on fossil fuels. Yet, despite the environmental, social, and economic benefits of waste heat recovery (WHR), it is not widely practiced due to a number of non-technical barriers.

This research aims to analyze governance instruments that local governments can use in order to proactively support the integration of WHR in local energy systems. Using a multiple-case study approach, WHR-supportive governance in Gothenburg (Sweden), Turku (Finland), and Rotterdam (Netherlands) is analyzed, applying a framework of six different governance modes: *Hierarchical Planning and Regulation*, *Market Facilitation*, *Market Provision and Promotion*, *Network Facilitation*, *Network Coordination and Advocacy*, *Network* and *Awareness Raising and Outreach.*

Multiple instruments that local governments can use to support WHR projects were identified in a pre-study of the case cities. A key difference was identified between the governance modes used by Gothenburg and Turku, both of which have municipally owned DH systems, as opposed to Rotterdam whose system is run by multiple private DH providers. This finding suggests that ownership of local DH structures has a major impact on governance options to support WHR. Taking into account further contextual factors, the replicability of governance modes and instruments identified is discussed. In conclusion, recommendations for local governments willing to support WHR in their context are provided, encouraging local governments to use their central position in local energy systems to connect and coordinate WHR-relevant actors, and to establish WHR-supportive planning and decision-making processes.

This contribution is the first work compiling governance instruments which local governments can use in order to support WHR and thus is particularly of interest for practitioners, but also relevant for researchers in the field. Further case studies on WHR-supportive governance would diversify the findings. The generalizability of the framework developed in this study, should also be further tested by analyzing local level governance in other sectors.


**Keywords:** waste heat recovery, district heating, energy governance, governance instruments, modes of governance

# Executive Summary

If not recovered, 'waste heat' that originates from industrial- and urban processes disseminates into the environment. Estimates on waste heat potentials indicate significant capacities, of around 20% of the total annual heat demands, for residential space heating and hot water preparation in the European Union could be met through the energy from wasted heat. While the recovery of waste heat at high temperatures, from activities such as metal processing or petroleum refineries, is practiced in several places, especially in Northern Europe, the recovery of waste heat at low temperatures, like from food processing, cold storage, data centers, or metro systems, has only been tested in few pilot projects so far. But when integrated into district heating systems, waste heat can replace large scale fossil fuel boilers that are commonly used at present. By reducing primary energy inputs in local heating systems, waste heat recovery (WHR) mitigates the environmental and social impacts of these systems. In addition, it contributes to local value capturing, and decreases dependence on fuel imports. Yet despite all these benefits, several barriers currently hinder the implementation of WHR projects. Mapping different types of non-technical barriers to WHR in this study, including *knowledge, cognitive, economic, legal and institutional barriers,* revealed that local governments are promising actors in addressing these barriers. They play a central role in local energy systems and have an interest in cross-sectoral energy efficiency improvements, which individual actors may not have.

For local governments willing to support WHR however, few resources on governance options exist so far. Theoretical studies on urban WHR are limited to technical aspects, and the sole prior case study on WHR related governance which was identified, is limited to the planning process, excluding the implementation of WHR projects.

Against the background of this knowledge gap, and the sustainability potential of WHR, the thesis aims to analyze the governance instruments that local governments can use to proactively support the implementation of WHR solutions. It does so by analyzing different modes of governance, as a logic through which governance instruments can foster WHR. It is guided by two main research questions:

***RQ1****: Which WHR-supportive governance instruments can be identified in earlier research?*

***RQ2:*** *How have three case cities supported WHR in the past and how are they supporting WHR at present?*

- *Which motivations stimulated WHR-supportive governance?*
- *Which barriers to WHR occurred?*
- *Which governance modes and instruments are applied to address barriers to WHR?*
- *Which contextual factors enabled WHR projects and WHR-supportive governance?*

*RQ 1* works as a preparatory research step for the multiple-case study at the core of this research. Cases analyzed in order to answer *RQ 2*, are the cities of Turku in Finland, Gothenburg in Sweden and Rotterdam in the Netherlands. While Turku has been a collaboration partner from the start of this project, the other two cities were chosen due to progressive activities regarding WHR mentioned in grey literature. In total 14 semi-structured interviews with mainly representatives of the city authorities and energy companies in the case cities were conducted. Data collection and analysis in both research steps was guided by an analytical framework that was developed based on the literature review.

WHR, within the scope of this thesis, is realized in district heating (DH) systems. DH systems connect heat sources with places of heat demand through transmission pipes, and traditionally are fueled by centralized, large scale boilers. Due to their flexibility towards heat sources, waste heat sources can be integrated in existing DH networks, and thus become part of the same

socio-technical system. Actors, infrastructures, and legal frameworks in WHR and DH, are expected to be closely related, however not identical.

The literature review found that local governments, based on their capacities, can take different roles to support the development of local DH systems. They can support DH as *planner and regulator* (through developing energy strategies, visions, goals or targets), *facilitator* (through financial or fiscal incentives, investing in city assets or pilot projects), *provider and promoter* (through self-governance, tariffs, acting as a large consumer), *coordinator and advocate* (through providing or generating data, facilitating partnerships) and through *awareness raising and outreach* (for DH, locally and on upper governance levels).
Other scholars that analyzed local energy and transition governance described different logics through which governance is realized and actors are coordinated. They distinguished three ideal-type modes of governance: *Hierarchical governance* that uses top-down steering, legitimized by authority, *network governance* that reaches shared objectives through trust and contracts in horizontal relationships, and *market governance* that uses economic incentives to motivate market agents.

In the analytical framework for this study, six different modes of governance to address barriers to WHR were developed from the interlinked roles and ideal-type modes of governance. These include: *Hierarchical Planning and Regulation*, *Market Facilitation*, *Market Provision and Promotion*, *Network Facilitation*, *Network Coordination and Advocacy*, *Network Awareness Raising and Outreach.*

In order to answer *RQ 1*, multiple examples of WHR-supportive governance instruments mentioned in academic and grey literature, as well as on online resources, were identified. They included energy goals and strategies, energy potential mapping, a waste heat registry, DH connection policy, self-governance in public procurement, investments in city assets, and facilitating partnerships. The most common instrument was to set up pilot projects. Further instruments suggested in theory, but not applied in practice yet, included obligations to recover generated waste heat, tax breaks and investment subsidies for WHR infrastructures.

The analysis of governance modes and instruments applied in the case cities, in order to answer *RQ 2* was done in two steps. In a first step, data from each case was analyzed separately. In a second step, similarities and differences between the three cases were identified.

The individual analysis showed high- and low-temperature WHR projects are realized to a different extent in the case cities. In Gothenburg high-temperature WHR is established while low-temperature WHR is not significantly addressed yet; in Turku, there is governance activity on developing both; and in Rotterdam, high-temperature waste heat is abundant, while DH demands are low, so governance activities currently focus on increasing DH connections.

The main motivation for WHR, across cases, is to reach municipal climate goals. Economic factors have been a driver for implementing WHR as well. Barriers that currently hinder WHR in the case cities, partly confirmed the barriers identified in literature. Some barriers identified complement prior findings, including a lack of knowledge on storage technology, insufficient DH connections, and context specific legal barriers, including unfavorable electricity taxation, and temperature requirements in DH systems.

Multiple governance instruments that are applied in the case cities, to explicitly, or implicitly address barriers to WHR, were identified. They cover the six governance modes of the analytical framework. In order to address institutional barriers to WHR, *Hierarchical Planning and Regulation*, mainly through goal setting, was applied. Knowledge and cognitive barriers were addressed by *Network Facilitation*, and *Network Coordination and Advocacy*. In order to address demand as a barrier, governance instruments reflecting a broad variety of governance modes were applied, including *Market Facilitation*, *Market Provision and Promotion*, *Network Facilitation*, *Network Coordination and Advocacy,* and *Hierarchical Planning and Regulation*. In order to address financial barriers, *Market Facilitation*, *Network Coordination and Advocacy* are applied by the case cities, and in order to address legal barriers, *Network Awareness Raising and Outreach* was used.

The results reveal a significant difference in the governance modes and instruments applied by Gothenburg and Turku, both with municipal owned DH systems, and Rotterdam, with multiple private DH companies. This difference suggests that ownership of local DH structures, has a major impact on governance options to support WHR.
Besides the ownership situation, further contextual factors enabled WHR, or WHR-supportive governance in the case cities, including financial support from national governance levels, existing infrastructures, financial and human resources, favorable electricity prices, and a proactive DH company. The replicability of the governance instruments identified is discussed on basis of these context specific factors. As a conclusion, the following recommendations for local governments willing to support WHR in their context can be made: Local governments should:

- Explicitly integrate WHR in municipal energy goals and strategies;
- Apply WHR-supportive, combined urban and energy planning including clear planning and decision-making principles;
- Establish systematic processes to assess and document local waste heat potentials;
- Make use of WHR opportunities in urban development projects;
- Initiate and facilitate partnerships that potentially lead to the realization of WHR projects;
- Address all WHR-relevant aspects with equal care: waste heat source(s), heat demand DH pipes and connections, financial resources, political support;
- Exchange experiences on technologies, business model, and governance approaches with other localities, for instance in city networks;
- Align strategies with upper governance levels.

Governance instruments and modes local governments can use to address different types of barriers in specific contexts are presented in the subsequent table.

| **Governance Instruments** | **Mode** | **Context** |
|---|---|---|
| To address institutional barriers to WHR | | |
| Define municipal **energy goals and strategies**<br>- Coordinate action across sectors<br>- Alignment with upper governance levels | *Hierarchical Planning and Regulation* | Any ownership structure<br>If limited authority: combine with other approaches |
| Combine urban and energy planning<br>Define **clear decision making principles**, e.g. 'energy hierarchy' | *Hierarchical Planning and Regulation* | Any ownership structure |
| Initiate or facilitate WHR-partnerships | *Network Coordination and Advocacy* | Any ownership structure |
| To address knowledge and cognitive barriers to WHR | | |
| Assess and document local WHR potentials systematically | *Network Facilitation* | Any context |

| | | |
|---|---|---|
| Collaborate with universities on mapping of local waste heat potentials | *Network Coordination and Advocacy* | Low human and financial resources |
| Conduct pilot and research projects, e.g. in collaboration with academia or potential technology provider | *Network Facilitation* | High human and financial resources |
| Exchange existing knowledge between cities, e.g. through city networks | *Network Coordination and Advocacy* | Low human and financial resources |
| To address financial barriers to WHR | | |
| Consider long-term benefits of investments in DH infrastructure | *All* | Any context |
| Invest in public WHR infrastructures<br>- Select business model and contract design carefully<br>- Distribute risks by decentralizing heat generation; using potentials of low-temperature DH (LTDH)<br>- Consider joint investments with waste heat provider | *Market Facilitation* | Sufficient financial resources |
| Facilitate long-term planning of private actors (e.g. through low-or zero-interest loans or long-term contracts and permits)<br>- Design contracts carefully | *Market Facilitation* | Insufficient financial resources |
| To address market related barriers to WHR | | |
| Raise awareness for policy needs at national governance levels | *Awareness Raising and Outreach* | Any |
| Procure recovered heat in public buildings | *Market Provision and Promotion* | High public heating demands |
| Stimulate heat trading by providing key infrastructures, e.g. transmission pipes | *Market Facilitation* | Sufficient financial resources |
| Arrange partnerships with third actors that can supply or procure recovered heat | *Network Coordination and Advocacy* | Low public heating demands |
| Support WHR integrative infrastructures and building designs (e.g. through requirements to assess WHR potentials, and use agreements, or building codes) | *Hierarchical Planning and Regulation* | City development projects |
| Participate proactively in the development and testing of WHR solutions | *Network Facilitation* | City development projects<br>Sufficient human and financial resources |
| Facilitate partnerships between third actors and provide them with WHR-relevant information to stimulate projects | *Network Coordination and Advocacy* | City development projects<br>Insufficient human and financial resources |

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## Abbreviations

| | |
|---|---|
| CHP | Combined Heat and Power |
| DC | District Cooling |
| DH | District Heating |
| DE | District Energy |
| EU | European Union |
| GHG | Greenhouse Gas |
| GIS | Geographic Information System |
| LTDH | Low-temperature District Heating |
| RE | Renewable Energy |
| REAP | Rotterdam Energy Approach and Planning |
| UNEP | United Nations Environment Program |
| WHR | Waste Heat Recovery |

# 1 Introduction

Waste is commonly defined as "a bad use of something valuable that you have only a limited amount of (Cambridge English Dictionary, 2020)." - Approximately two thirds of global primary energy production dissipates as heat into the environment, and is termed energy 'losses' (Grübler et al., 2012). Such energy losses include large shares of 'waste heat' from industrial or urban sources that could however, still be used. Estimates on waste heat potentials indicate significant capacities – approximately 20% of the total annual heat demands for residential space heating and hot water preparation in the European Union (EU) – could be met through waste heat (Papapetrou et al., 2018; Persson & Averfalk, 2018). Replacing conventional energy sources through energy from waste heat, can thus reduce the primary energy inputs in local systems. This has benefits from both an environmental and social perspective. At present, 90% of primary energy inputs in the global heating sector rely on the combustion of fossil fuels (IEA, 2019a). Greenhouse gas (GHG) emissions from fossil fuel combustion in this sector contribute significantly to climate change (IPCC, 2014), which is associated with global environmental and social impacts (Field et al., 2014). Furthermore, waste heat recovery (WHR) has additional benefits at the local level: it contributes to local value capturing and a decreased dependence on fuel imports. Yet, despite these benefits, WHR is not widely practiced (Persson, 2015). A number of non-technical barriers currently hinder the implementation of WHR projects (ReUseHeat, 2019a).

However, action at the local level is needed and city governments are perceived to be crucial in implementing sustainability transitions (Bulkeley, 2010; Hodson & Marvin, 2010). Energy demands are expected to increase in the future (IEA, 2019b), and a significant share of this global energy demand is expected to come from cities (IRP, 2018), making them 'key enablers of change' (EEA, 2019). In terms of WHR, cities and regional governments seem well suited to promote the implementation of WHR in local energy systems – they have significant potential for WHR, as waste heat sources and heating demands occur in close spatial proximity. They also have an interest in local value capturing and cross-sectoral energy efficiency improvements that individual actors might not have. In addition, many municipalities play a central role in local energy systems through operating municipal energy companies, investing in energy infrastructures, or coordinating urban energy planning. To date, however, there is a lack of research and information on WHR-supportive governance options, which limits effective action at the local level.

Against the background of the benefits WHR promises, at both the local and global level, analyzing WHR-supportive governance is clearly needed. Recommendations for local governments, willing to support WHR in their context, are therefore needed in order to utilize the significant potential of waste heat.

## 1.1 Aim and Research Questions

The thesis aims to analyze governance instruments that proactively support the local implementation of WHR solutions. The research analyzes different instruments and modes of governance that reflect different logics through which local governments steer actors and foster WHR. It is guided by two research questions:

***RQ1****: Which WHR-supportive governance instruments can be identified in earlier research?*

***RQ2:*** *How have three case cities supported WHR in the past and how are they supporting WHR at present?*

- *Which motivations stimulated WHR-supportive governance?*
- *Which barriers to WHR occurred?*
- *Which governance modes and instruments are applied to address barriers to WHR?*

- *Which contextual factors enabled WHR projects and WHR-supportive governance?*

Case study cities analyzed in this thesis are Turku in Finland, Gothenburg in Sweden and Rotterdam in the Netherlands. While Turku has been a collaboration partner from the start of this project, the other two cities were chosen due to their progressive activities regarding WHR mentioned in grey literature and websites (Celsius, 2020b; UNEP, 2015). The selection of the cases is further outlined in the method section (Chapter 4.1.2), a summary of their characteristics is provided in Appendix 3.

*Table 1 Overview on the case cities*

| City | Population | WHR projects |
|---|---|---|
| **Gothenburg** | 570.000 | • WHR from St1, former Shell, **refinery**, since 1980<br>• WHR from Preem **refinery**, since 1998<br>• WHR from sewage water, since 1983/1985 |
| **Turku** | 190.000 | • WHR from sewage water, since 2009<br>• Pilot project two-way DH (65 °C) in city development district Skanssi<br>- Currently assessed: WHR from Neste **refinery** in Naatali |
| **Rotterdam** | 650.000 | • WHR from Shell refinery, since 2018<br>- Currently assessed: WHR from **data centre** |

*Sources: see full table in Appendix 3*

The thesis takes a case study approach to investigate how cities are currently supporting WHR solutions, by analyzing the approaches used in Turku, Gothenburg and Rotterdam. The case study is prepared using a prior research step (*RQ 1*) that provides an overview on WHR governance options, in order to benchmark activities in the case studies. The three cases represent different development stages and actor constellations in relation to WHR, which shall provide a broader variety of governance instruments applied in different contexts.

The geographic location of these cities in Western and Northern Europe, as well as their industrialized economies, limits their representativeness in terms of cultural, economic and legal frameworks. From an analytical perspective, however, the replicability of learnings is possible, while from the discussion of governance instruments, methods for addressing certain barriers can be generalized. This is discussed further in Chapter 4.2.

Data collection for the preparatory research-step (*RQ 1*) was exploratory and exemplary. It does not claim completeness. Due to language barriers, mainly English and some German sources were used. This created an overrepresentation of projects in Europe and North America. Similarly, data collection in the actual case studies (*RQ 2*) was restricted and relied mainly on interviews.

The study focusses on WHR projects in 'open' DH systems that are connected to dwellings of multiple owners and accessible for any actor from a market perspective. This excludes WHR projects of individual actors or energy exchange between private companies. These projects contribute to regional energy efficiency as well. However, they primarily have exclusive benefits for the respective actors involved, which does not match the understanding taken by this study, which views open DH systems as a public good.

The study focusses on WHR for the purpose of heating. Two of the case cities, Turku and Gothenburg, additionally provide cooling services from waste heat. From a technical perspective, heat recovery for district cooling (DC) or electricity generation is possible too, and may be sustainable in places with low heating demands. Due to transformation losses, however, WHR for heating purposes is more favorable. Due to the equivalence of DH and DC systems (Frederiksen & Werner, 2013), aspects discussed in the thesis may be equally applicable for DC from waste heat or cold.

## 1.2 External Partner and Target Audience

This thesis has been written in cooperation with ICLEI (Local Governments for Sustainability), a global network of sub-national governments. ICLEI aims to facilitate knowledge exchange and capacity building between sub-national governments (ICLEI, 2019a). The research contributes to the Circular Turku project, which aims at developing a regional circular economy roadmap (ICLEI, 2019b). In addition to accelerating the circular transition of five key sectors in Turku, including energy systems, this project is expected to generate replicable learnings that can be adopted by other localities (ICLEI, 2019b). The collaboration with ICLEI created the opportunity to identify a topic that is of value for the city of Turku, and as well for other cities. With ICLEI being an international network, the collaboration increases the chance that the results of this research reach the intended audience, local governments and associated decision-makers around the world.

The results might also be of interest to policy makers at higher governance levels, such as national and supranational governments. Furthermore, they may be valuable to any parties potentially involved in WHR projects, including private energy companies, property developers or owners, and urban planners. In addition, researchers in the field of urban energy governance and planning as well as public administration, may also be interested in the results as well

## 1.3 Ethical Considerations

My research is supported by the organization ICLEI and contributes to their current project, the development of a circular strategy for the city of Turku. ICLEI and the city of Turku have been consulted when defining the scope and focus of the thesis to ensure it is of practical use for them. However, the results were collected and analyzed independently, so that results would not be adversely influenced by these parties.

Concerning data collection, all interviews were voluntary. All interviewees were informed about the purpose of the study and the manner in which data would be used. Prior to the interviews, they gave consent to the recording of the conversation. As with all data, the records were stored on a personal, password protected device. Interview protocols were sent to the participants following the conversations. In this way the opportunity has been given to check for sensitive information. If data seemed politically sensitive, a considerate interpretation and objective presentation has been used to the best of the author's ability. In individual cases, parts of the analysis to which interviewees contributed, has been sent out prior to publication. The presentation of the respondents is anonymized. In this way, there is no cause to believe that the participants may suffer any disadvantage or damage from their participation in the study.

## 1.4 Disposition

After the subject and this work were introduced in *Chapte*r 1, *Chapter 2* defines waste heat and provides background information on WHR in DH systems. *Chapter 3* reviews existing knowledge on stakeholder specific barriers to WHR and earlier research on WHR-supportive governance. As not much prior research on WHR-supportive governance was identified, it also reviews approaches taken by other scholars to analyze urban energy and transition governance. Having been identified in the literature, as common framework elements, three ideal-type modes of governance: 'hierarchical, network, and market governance;' are introduced, describing the logic through which governments steer action. Based on the literature review, the analytical framework for the study is developed in *Chapter 3.4,* consisting of six different modes of governance that local governments can apply to support WHR, including: *Hierarchical Planning and Regulation*, *Market Facilitation*, *Market Provision and Promotion*, *Network Facilitation*, *Network Coordination and Advocacy*, and *Network Awareness Raising and Outreach.*

*Chapter 4* presents the research design, methods of data collection and analysis of this study. In *Chapter 5* results of the pre-study, including examples of WHR-supportive governance instruments, are presented. *Chapter 6* analyses results from data collection from the case cities. It begins by providing an overview of WHR developments in each of the cases, and then analyses governance modes and instruments applied by the cities in order to address different types of barriers, including *institutional, knowledge, financial, market* and *legal barriers.*

In *Chapter 7* the results are discussed. The discussion includes a reflection on the influence of different ownership structures on WHR-supportive governance in the case cities. After outlining the general relevance of this work, the replicability of the learnings in other contexts is discussed as a central contribution. *Chapter 8* presents final conclusions by summarizing recommendations for other localities and ideas for further research. Figure 1 illustrates this outline.

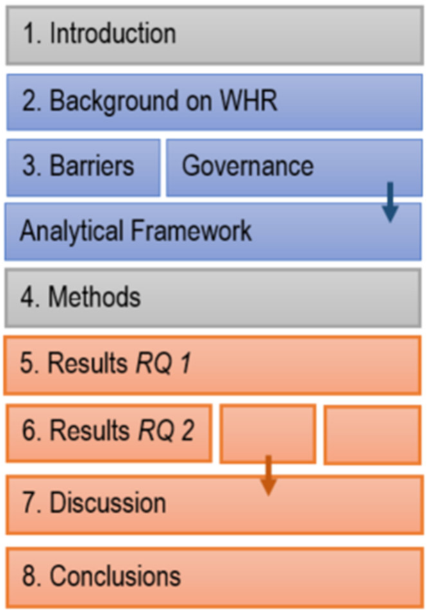



*Figure 1 Disposition (own illustration)*

# 2 Waste Heat Recovery

The literature review introduces WHR as a sustainable heat source in semi-urban and urban energy systems. It defines waste heat and introduces different waste heat sources. It demonstrates fundamentals to DH systems as a way to recover waste heat. Lastly, it gives an overview on actors typically involved in WHR integrating DH systems.

## 2.1 Waste Heat as a Sustainable Energy Source

Waste heat is heat that originates from processes or activities for which it does not have further use. Usually, waste heat is ventilated into the ambient air, cooled in nearby water bodies, or simply disseminates into the environment (Goldstick & Thumann, 1986).

As taught by the principle of energy conservation, energy cannot be lost. It can only be transferred from one form to another. If not hindered, thermal energy disseminates into its environment in order to balance temperature differences (Goldstick & Thumann, 1986). Thermal energy at high temperatures has a high quality and thermal energy at low temperatures has a low quality. Energy of low quality cannot be transferred to high quality without energy inputs. This means, heat cannot fully be re-used. 'Heat recycling' is only possible with energy inputs, or at lower temperature levels.

Among the overall heat released by an industrial process, avoidable and unavoidable excess heat can be distinguished (Bendig et al., 2013). Unavoidable excess heat cannot be avoided through efficiency improvements. It is called residual heat. The share of the residual heat that is still 'useful' from a theoretical perspective, called exergy, depends on temperature differences to ambient levels (Bendig et al., 2013).

Even though WHR is seldom restricted from a technological perspective, it does not makes sense from an economic perspective in every case (Brueckner et al., 2014). The 'economic' waste heat potential is determined by quality, quantity and stability of the heat supply. Due to costs of transmission pipes and distribution losses, the spatial distance between heat source and heat demand additionally impacts the economic feasibility of WHR projects (Brueckner et al., 2014). Accordingly, waste heat will here be understood as *residual heat that can be recovered from a technological and economical perspective* (see Figure 2).

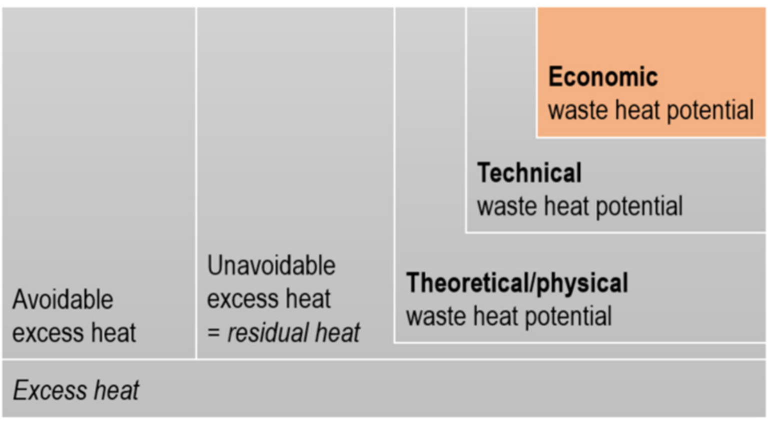



*Figure 2: Types of waste heat potential*

*Source: Created by the author after Brueckner et al. (2014) and Bendig et al. (2013).*

Other scholars have used the terms 'residual' or 'excess heat recovery' when referring to WHR (Broberg et al., 2012; Lygnerud & Werner, 2018; Päivärinne et al., 2015; Persson, 2015). Avoiding the term 'waste' can prevent the association with 'not-of-value'. Despite the fact he value of waste heat sources need to be communicated to the wider public, the terms cannot be used interchangeably, according to the definition presented.

Some authors include Combined Heat and Power (CHP) or waste to energy plants when defining waste heat sources, also termed energy recycling or secondary energy supply (Frederiksen & Werner, 2013; Persson, 2015). They perceive heat as a by-product of electricity generation and solid waste management. From a sustainability perspective, however, both electricity and solid waste generation are favorably reduced in the future. Hence heat from these sources is limited. In Europe, recovering heat from CHP and waste to energy plants is quite common in comparison to industrial waste heat sources (Persson, 2015). This builds an argument for emphasizing on industrial and urban waste heat sources in particular in this research.

To date, most literature on WHR focuses on industrial waste heat (Al-Rabghi et al., 1993; Brueckner et al., 2014, 2015; Miró et al., 2015), and the utilization of 'high-temperature' waste heat from industries, like petroleum, pulp and paper, chemical, steel and metals industry is established in several locations across Europe (Persson, 2015; Werner, 2017). One third of the industrial waste heat potential in Europe, however, is 'low-temperature' waste heat, below 100 °C (Papapetrou et al., 2018). It occurs in industries like food processing, tobacco, and printing and is utilized less frequently to date (Papapetrou et al., 2018). Estimations on WHR potentials highly vary in scope and results. No global assessment of WHR potentials exist. For Europe, WHR potential from industries is estimated at 1.08 EJ/year by Papapetrou et al. (2018), while the amount of industrial waste heat currently recovered in EU27 is estimated at 0.025 EJ/year by Persson (2015). This shows how small the share of waste heat is that actually is recovered to date. Brueckner et al. (2014) reviewed different studies estimating waste heat potentials on a regional level, they indicate 5 to 30% of industrial heat demands could be covered by recovered waste heat. For individual cities this range is even higher. Karner et al. (2016) demonstrated up to 32 % of total heat demands could be covered through WHR in four Austrian project regions.

Recent efficiency improvements in district heating (DH) systems, which are discussed in more depth in Chapter 2.2, enable the recovery of heat sources below 100 °C. The opportunity to utilize heat sources at lower temperatures, allows to recover not only industrial, bur also urban heat sources, like sewage water (Hepbasli et al., 2014), waste water treatment plants (Neugebauer et al., 2015), metro systems (Revesz et al., 2016) or data centers (Ebrahimi et al., 2014) in DH. The potential of urban waste heat for European Union (EU) was estimated at 1.2 EJ/year by Persson and Averfalk (2018). This equals 10 % the EU28's annual total energy demand for space heating and hot water preparation in the residential and service sector, estimated at 13.1 EJ (Persson & Werner, 2015). Adding the 1.08 EJ/year industrial WHR potential estimated by Papapetrou et al. (2018), this leads to an overall WHR potential of roughly 20 % of European heat demands for space heating and hot water preparation.

*Table 2 Examples of waste heat sources*

| | **High-temperature** (> 100°C) | **Low- temperature** (< 100°C) |
|---|---|---|
| **Industrial sources** | • Steel and metals<br>• Petroleum refineries<br>• Chemicals<br>• Pulp and paper | • Food processing<br>• Tobacco<br>• Printing |
| **Urban sources** | • None identified | • Sewage water<br>• Metro systems<br>• Data centers<br>• Refrigeration and cooling systems (supermarkets, food storage, laboratories) |

*Source: See references in text*

But where is this waste heat best used? It depends on both the temperature of the heat source and the temperature demand at the heat sink. Ideally, temperature differences are high enough to cover the demand, but should not be higher than needed, because then, waste heat can again be created. Low temperature level demands are defined below 100 °C (Frederiksen & Werner, 2013), and heat deliveries around 90 °C are typically needed for space heating and hot water preparation (Frederiksen & Werner, 2013). However, in modern buildings, deliveries around 30 °C are sufficient for space heating (Lund et al., 2014). In addition to residential and service sector heat demands, 27% of industrial heat demand occurs on low temperature levels (Brueckner et al., 2015). Applications are washing, rinsing, and food preparation. Further heat demands occur from agricultural heating for greenhouses or fish ponds, sewage treatment or biogas reactors (Frederiksen & Werner, 2013). In Northern European countries specifically, outdoor ground heating is used for snow and ice removal on pavements and streets to avoid accidents (Frederiksen & Werner, 2013).

It can be concluded that despite uncertainties on the exact potential of industrial and urban waste heat, replace primary energy inputs could be replaced significantly by WHR. As spatial proximity between heat source and sink plays a major role for the economic feasibility of projects, waste heat potential needs to be assessed on a regional or local scope. The following chapter introduces DH systems as the most common way to deliver heat from places of heat generation to places of heat demand.

## 2.2 Utilizing Waste Heat in District Heating

Waste heat can be utilized in DH either directly or by ‘upgrading’ it. The direct utilization is also referred to as passive heat recovery (Brueckner et al., 2015). Heat exchanger transfer heat from the heat source to the transmission medium. Most commonly in DH, the transmission medium is water (Frederiksen & Werner, 2013). Pipes, pumps and storage facilities then supply the heated water to where it is demanded and return cold water to the heat source where it is reheated. Through heat pumps heat sources at lower temperatures than the transmission medium can be utilized in DH too. However, this active WHR requires additional energy inputs in form of electricity (Brueckner et al., 2015). The environmental impact of such WHR thus depends on the local electricity mix (Frederiksen & Werner, 2013)-

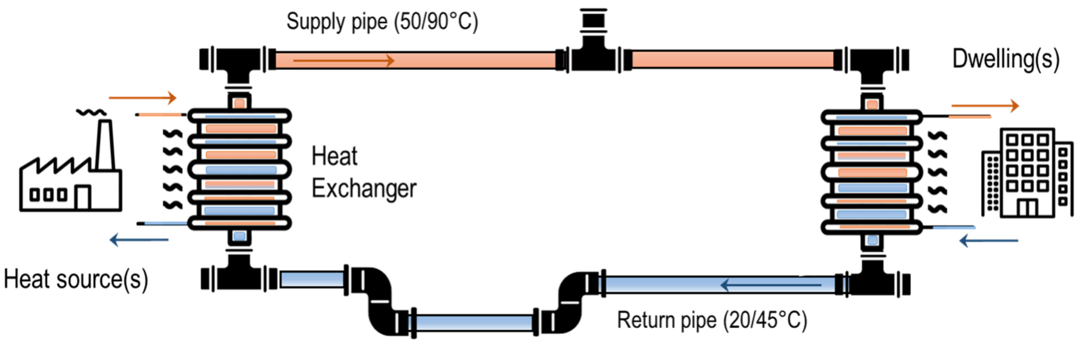



*Figure 3 DH system (own illustration)*

Heat can be exchanged between different 'urban functions', activities taking place in cities, if their patterns of heating and cooling differ. A particular opportunity exists for instance for heat exchanges between supermarkets that require cooling and residential housing that require heating (van den Dobbelsteen et al., 2018). Accordingly, heat can be exchanged within or between different buildings. DH at district or city level can solve discrepancies of energy balance at neighborhood level, as a broader mix of urban functions, like shopping centers, swimming pools or ice skating arenas, might be available (van den Dobbelsteen et al., 2018).

Internationally, DH is the label for a common heat supply for a particular district or area (Frederiksen & Werner, 2013). In the US where DH and DC are prevalent, district energy (DE) oftentimes is used as a term to combine the labels. Institutional DH systems are made for large hospitals, university campuses or military bases and only have one owner. In Europe, only systems that connect several building owners qualify as termed DH (Frederiksen & Werner, 2013). Following this distinction, only systems that are 'open' to several end-customers are regarded in this study.

Distribution losses occur between the heat supply units and the customer sub-stations, depending on spatial distances, and the properties of distribution pipes, such as insulation properties and diameter (Frederiksen & Werner, 2013). In addition, distribution losses are influenced by the transmission temperatures in relation to the surroundings. In traditional DH, supply temperatures are around 90 °C (Frederiksen & Werner, 2013) while they are at 30-70 °C in so called 'low-temperature DH' (LTDH) systems (Lund et al., 2014). Return temperatures are typically around 40 °C in conventional DH (Frederiksen & Werner, 2013), between 20-40 °C in LTDH (Lund et al., 2014). Due to a lower temperature difference to the surroundings, LDTH show fewer distribution losses, and thus are more efficient (Lund et al., 2014). In addition, they can utilize lower temperature heat sources than conventional systems, for instance reheating water from 20 °C back to 50 °C with a 60°C heat source.

Traditionally, DH systems were characterized through 'central' heat generation (Werner, 2017), utilizing the benefits of economy-of-size compared to domestic boilers (Frederiksen & Werner, 2013). The possibility to use local fuels and waste heat was a fundamental idea when DH was firstly introduced in Scandinavia (Frederiksen & Werner, 2013). In the last decade, renewable energy (RE) sources, like geothermal wells, solar collectors and biomass fuels as heat sources additionally became important (Werner, 2017). DH systems could be adopted due to their flexibility towards the supplying heat source (Frederiksen & Werner, 2013). Combining several heat sources, including RE and waste heat, refers to 'decentralized' heat generation in DH (Frederiksen & Werner, 2013). However, this is not widely applied yet. Most DH system in Russia and China, and several DH systems in the EU still rely on large fossil fuel, primary energy boilers (Werner, 2017).

Systems of centralized heat generation from fossil fueled CHP are described as 1st and 2nd generation of DH. Decentralized DH from CHP including biomass and solid waste boilers are described as the 3rd generation. Most recently, the 4th generation DH has been launched (Lund et al., 2014). It is characterized by low temperatures (in LTDH), and decentralized, RE sources. The role of end-costumers is expected to change in 4th generation DH, as they can become 'prosumers' (Brange et al., 2016; Lund et al., 2014), in analogy to the concept that already exists in electricity systems for solar power feed-ins (Parag & Sovacool, 2016). Prosumers in DH are connected to the system in a two-way manner, in addition to obtaining heat, they supply (waste) heat to the grid (Lund et al., 2014).

In sum, LTDH, by introducing the 4th DH generation, will make a wide range of energy exchanges and WHR possible in the future.

Beyond their ability to integrate waste heat and RE energy sources, DH systems have many benefits in general. It is increasingly acknowledged that DE, including DH and DC, is the most-cost effective way to meet emission targets (Rao et al., 2017). DE systems increase the local competitiveness, create revenues, and keep opportunities for further local value creation open (Rao et al., 2017), and are seen as resilient and reliable (UNEP, 2015). Through their cost-effectiveness DE systems in addition can address and mitigate fuel poverty (Rao et al., 2017). Furthermore, DE contribute to indoor and outdoor air pollution reduction (UNEP, 2015). Table 3 summarizes the benefits of WHR and DH.

*Table 3 Summary of benefits of WHR and DH*

| | **Driver** | **Economic Benefits** | **Social Benefits** | **Environmental Benefits** |
|---|---|---|---|---|
| **WHR** | Increased local/regional energy efficiency | • Local value capturing | • Decreased dependence on fuel imports<br>• Reduction of social impacts in supply chain of primary energy generation | • GHG mission reduction<br>• Reduction of environmental impacts in supply chain of primary energy generation |
| **DH** | Fuel flexibility | • New revenue streams<br>• Increase in local competitiveness<br>• Opportunity for further local value creation | • Resilience<br>• Reliability<br>• cost-effectiveness > addressing fuel poverty | • Reduction in indoor and outdoor air pollution |

*Source: Created by author based on Rao et al. (2017) and UNEP (2015)*

Despite the benefits outlined, most local energy systems are far from taking full advantage of local waste heat potentials, and the implementation of LTDH happens rather slowly (Lund, 2018). The first systems will be operational soon, for instance in Brunnshög Lund, Sweden and Høje-Taastrup, Denmark (COOL DH, 2019).

DH systems as part of large energy systems can be perceived as 'Large Technical Systems', as for instance by Palm (2006). Large Technical System change rather slowly, as new technology cannot be introduced without considering pre-existing technological parts (Hughes, 1987). If one technology is chosen it will continue to affect the development of the system for a long time. This is referred to as technological path dependence (David, 1988). Large technological systems are 'socio-technical systems'. Social aspects, such as cultural and legal frameworks and actors, are shaping them just as their technical components. The following reviews actors typically involved in WHR in DH.

## 2.3 Actors in Waste Heat Recovery

Depending on the world region different DH ownership models are present. Initially, in the US most systems were privately owned, in Europe municipal ownership and in the former Soviet Union and China state owned models were common (Werner, 2017). The lack of financial resources and experience prevented further expansion of DH in most European countries. Only municipalities in Finland, Sweden, and Denmark had a favorable financial situation based on the fact they could apply designated taxes for financing municipal responsibilities, and additionally showed strong commitment for DH (Werner, 2017). Across the EU, processes of market liberalization caused an increase in private or partly private systems (Werner, 2017). Zeman & Werner (2004) identify eleven different ownership models for DH in Europe. The main ownership models are public, private and a public-private hybrid (Rao et al., 2017). One distinct characteristic of DH systems is their nature as natural monopolies (Palm, 2007). There is only room for one company in a geographically limited area. As investments in DH systems are very large it is more cost-effective for existing DH companies to expand their network then for new companies to enter the market.

Figure 4 provides a schematic representation of the stakeholder structure of WHR in DH. In some cases, one energy company owns and operates the DH system. In others, the *owner* of the DH infrastructure differs from the *operator*, however, the owner typically keeps some decision making power. Depending on the business model, the owner, operator or an additional external party acts like an *investor* that invests in the development of the DH system, or WHR technology. The operator either generates heat to sell to the *end-customer* or purchases heat to sell. When purchasing heat, the DH operator becomes a *customer* that buys, for instance waste heat from a *waste heat provider*. The waste heat provider might be public, in the case of WHR from sewage water, public hospitals or sports facilities, or private, for instance in case of waste heat from industrial facilities or data centers.

*Policy maker*s on different decision making levels further influence the system. National or supranational policy influences energy markets and pricing structures. Furthermore, national jurisdiction determines the level of responsibility local authorities have and which energy related tasks they are mandated to fulfil or not.

*Local government*s can be involved in DH through policy and regulation. Additionally, they can be involved as owner of local energy companies. In some cases, municipalities have financial resources to spend on public infrastructures like DH. Where local governments have limited financial resources, they can influence DH through corresponding urban planning (UNEP, 2015). If they are part of the local community, most of the presented stakeholder groups, including waste heat provider, end-customer, energy companies and investors, are represented, or even controlled, by local authorities. These connections give local authorities a central position in local WHR networks.

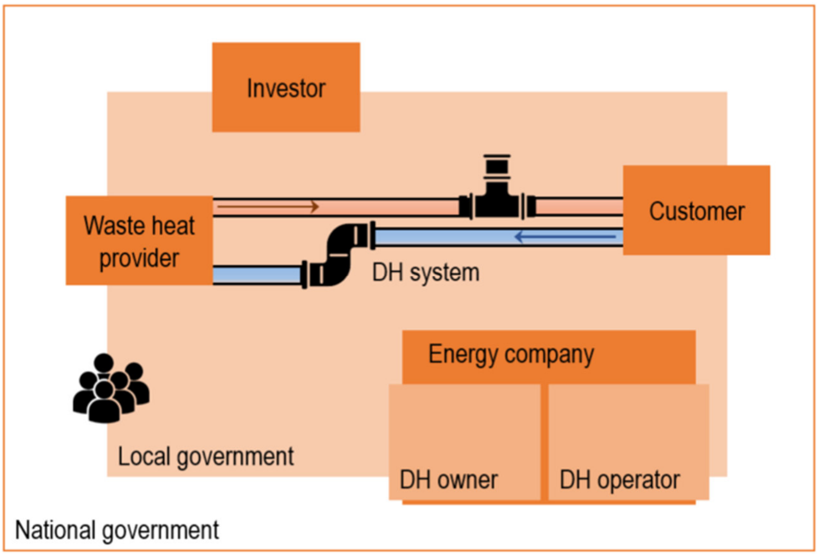



*Figure 4 Stakeholder structure for WHR in DH (own illustration)*

After introducing waste heat as a sustainable heat source and demonstrating the centrality of local governments in local WHR systems in DH, prior research on WHR-supportive governance at local level is reviewed in the following chapter. It is prepared by a review on stakeholder specific barriers to WHR.

# 3 Governance of Waste Heat Recovery

In order to give an overview on which factors WHR-supportive governance needs to address, this chapter firstly introduces prior research on barriers to WHR (Chapter 3.1). It then summarizes earlier research on WHR-supportive governance, and, as not much prior research on WHR-supportive governance was identified, reviews approaches taken by other scholars to analyze urban energy and transition governance (Chapter 3.2). Three ideal-type modes of governance, identified as a common framework, are introduced. They describe the logic through which governments steer action, including 'hierarchical, network and market governance' (Chapter 3.3).

Finally, the findings from all chapters are brought together in Chapter 3.4. An analytical framework for the study is developed by interlinking the three ideal-type modes of governance with five roles local governments can take to support WHR based on their capacities. In total, six different modes of governance are described that local governments can apply to address different types of barriers to WHR.

## 3.1 Earlier Research on Barriers to Waste Heat Recovery

Multiple non-technical factors hinder the implementation of WHR projects at present. As many barriers to WHR turn into enablers for WHR when they addressed, this chapter mainly focuses on barriers to WHR. Barriers are best understood in their context. For this reason, they are presented specific to each stakeholder group in the following.

The barriers identified were categorized into the following categories:

- *Knowledge barriers*, including the lack of knowledge or awareness on technology, business model or governance options; lack of context specific data,
- *Cognitive barriers*, connected with the lack of trust due to the newness of a solution,
- *Financial or business barriers,* including financial risks, and barriers based on current business models,
- *Market related barriers*, including competition due to current market structures,
- *Legal barriers,* including legal restrictions,
- *Institutional barriers,* including to a lack of legislation or clear definition of responsibilities, processes and goals.

From the perspective of **energy utilities** that own or operate DH systems, knowledge and experience on how to utilize urban waste heat is limited (ReUseHeat, 2019a). The maturity of technologies strongly varies, and especially the recovery of low-temperature waste heat sources is not sufficiently tested yet (ReUseHeat, 2019a). High investment costs with long payback periods make WHR investments unattractive to this stakeholder group (ReUseHeat, 2019a). In addition, WHR may compete with existing business models of selling heat (Päivärinne et al., 2015). Especially, if large investments into energy infrastructures, like CHP have been made recently or DH systems run over capacity, there is no incentive to invest in WHR. In addition, WHR competes with other heat sources which partly are supported by subsidies at present, such as subsidies for RE, electric heat pumps, biomass-fueled CHP plants or waste incineration (Lygnerud et al., 2019; Lygnerud & Werner, 2018; Kelly & Pollitt, 2010). The inclusion of WHR in national or local support programs could additionally help to overcome financial barriers. However, at present, no such funds exist (ReUseHeat, 2019a).

When setting up a business model with potential waste heat providers discrepancies in the perceived value of the waste heat were perceived as an issue (ReUseHeat, 2019a). The lack of measurement and verification skills made it hard to arrive at mutually accepted business models or contractual arrangements in several cases (ReUseHeat, 2019a). A lack of best practices on how to distribute risks and benefits has been described (Lygnerud et al., 2019; Moser et al., 2016). An additional investment risk, is uncertainty about the competitiveness of WHR in the future due to changing primary energy prices over time (Blömer et al., 2019), technological developments or future regulations favoring other heating systems (Kelly & Pollitt, 2010). According to Lygnerud et al. (2019) the current lack of legal frameworks or standardized procedures poses a cognitive barrier to WHR projects, especially for state or municipality owned companies that strongly orient themselves on national level frameworks.

From the perspective of **investors**, which can be represented by energy utilities but also by a separate party, decisions whether to support a WHR project or not depends on the taxation situation, the cost of the project and predictions on the price at which the energy can be sold (ReUseHeat, 2019a). Possible incentives could be public support through funding or risk mitigation, for example public Risk Sharing Facilities (ReUseHeat, 2019a). Qualifying project investments as green loans or linking them to tradable Energy Efficiency Certificates could further stimulate investments (ReUseHeat, 2019a).

From the perspective of **customers** of recovered energy, which can be energy utilities that purchase heat from a waste heat provider or end customers, the immaturity of WHR technologies poses a cognitive barrier (ReUseHeat, 2019a). Uncertainties about the technology is seen as an issue when applying for loans (ReUseHeat, 2019a). The same applies to decisions on purchasing recovered heat. The termination of operations by the waste heat provider can interrupt heat supply (Grönkvist & Sandberg, 2006; Lygnerud et al., 2019). Back-up systems are needed to cover temporary production stops (Päivärinne et al., 2015).

Potential **waste heat provider**, similar to the energy utilities, oftentimes lack information on WHR options at decision making level (Brueckner et al., 2014; ReUseHeat, 2019a). Corporate investments decisions are often short-term and seldom based on life cycle costs which would make long-term investments like WHR more attractive (Pehnt et al., 2010). The relevance of WHR for the potential waste heat supplier might be low. If WHR disturbs the core business this is a large obstacle (Pehnt et al., 2010). The competence to initiate or implement WHR projects might be limited. Economic incentives might be lacking and currently there is no regulation enforcing action in place (Pehnt et al., 2010).

Reasons to promote WHR from the perspective of **policy makers** are internal and external motives to reduce GHG emissions and promote resource conservation. However, lacking knowledge on technological opportunities and policy options pose a barrier (ReUseHeat, 2019a).

The liberalization of energy markets has decreased the power **local governments** have over local energy market and infrastructures. Consequentially, centralized and strategic coordination decreased (Hawkey & Webb (2014). If local governments have no mandate regarding energy related decisions this poses a barrier in the first place (UNEP, 2015; Grönkvist & Sandberg, 2006). Defining local governments' responsibility in regard to WHR could address this issue (Lygnerud et al., 2019). The institutionalization of WHR inclusive energy planning, through energy strategies, visions, or specialized, cross-departmental working groups can enable WHR, as e.g. shown by the city of Rotterdam (Lenhart et al., 2015). In contrast, lacking awareness on available waste heat sources and WHR technologies poses a barrier to WHR (Grönkvist & Sandberg, 2006). Additionally, the lack of capacity and know-how for the implementation of projects (Hawkey & Webb, 2014; Krasatsenka et al., 2017). Short political planning horizons (Lygnerud et al., 2019) with changing political and financial climates in public institutions (Lenhart et al., 2015) can furthermore prevent continuous support for WHR. Table 4 summarizes the presented stakeholder specific barriers to WHR

*Table 4 Stakeholder specific barriers to waste heat recovery*

| Stakeholder | Barriers[I] |
|---|---|
| Energy Utilities (Operator and/or owner of DH system) | • High investment costs with long payback periods (financial)<br>• Competition with business of primary heat provision (business)<br>• Competition with heat generation from other energy sources (market)<br>- Uncertainty about the competitiveness of WHR in the future (changing energy prices, technological developments, future regulations) (market)<br>• Limited knowledge on and experience with technology (knowledge)<br>• Immaturity of technology (cognitive barrier)<br>• Lack of best practices on how to distribute risks and benefits (cognitive/knowledge)<br>• Lack of standardized procedures or legal frameworks (cognitive barrier) |
| Investor | • Long payback periods (business)<br>• Lack of support in funding and risk mitigation (financial)<br>- Unpredictability of energy price developments (revenues) and taxation (financial) |
| Waste heat (end-)customer | • Awareness on maturity of technology (cognitive barrier)<br>- Risk of unstable supply (e.g. temporary production stops and termination of operations) (financial)<br>- Competition with heat from other heat sources (market) |
| Waste heat provider | • Lack of awareness on technological options (knowledge)<br>• Short-term investments decisions (business)<br>• Lack of relevance or even disturbance through WHR (business)<br>• Lack of competency to initiate or implement projects (knowledge)<br>• Lack of economic incentives (financial) |
| National level policy maker | • Lack of awareness on technological opportunities and policy options (knowledge)<br>- Changing political and financial climates (institutional) |
| Local government | - Lack of mandate (institutional/legal)<br>- Lack of planning control on liberalized energy markets (institutional/legal)<br>• Lack of awareness and knowledge on technological opportunities and policy options (knowledge)<br>• Lack of awareness on heat source availability (knowledge)<br>• Lack of capacity and know-how for the implementation of projects (knowledge)<br>• Lack of institutionalized responsibilities and planning procedures (institutional)<br>- Short political planning horizon and changing political and financial climates (institutional) |

*Sources: in text*

[I] Barriers local governments can theoretically influence with bold bullets.

Summarizing, multiple barriers for different stakeholder groups currently hinder WHR projects. Some are barriers none of the stakeholder groups can influence, such as the predictability of energy price developments, others are determined by upper governance levels, such as jurisdiction or regulation of energy markets. Local governments can influence some barriers directly, such as the institutionalization of responsibilities and planning procedures. Further barriers, lie in the realm of local governments, as they can be influenced by actors that local governments have control on or can build relationships with. In sum, most of barriers can, at least theoretically, be influenced by local governments (highlighted in Table 4 with bold bullets). The fact that local governments have such a central position in relation to barriers to WHR, highlights the potential of proactive, WHR-supportive governance and thus the relevance of this study. In the following chapter, existing research on WHR governance is reviewed.

## 3.2 Earlier Research on Governance of Waste Heat Recovery

Local governments include the governments of cities and regions. While the exact terminology often varies, local governments are the lowest tier of administration within a state. They act according to legislation and directive by upper governance levels, which can be federal, national or supranational governments of multiple states. The autonomy of local governments greatly varies between countries.

The idea that local governments are crucial in implementing societal sustainability transformations was first formulated in the Agenda 21 at the conference in Rio 1992 (UN, 1992). Sustainability transformations, as targeted by the Agenda 21, include transitions in all societal sub-systems, such as food, mobility and energy (UN, 1992). Local government' s activities in these areas bear the possibility to adapt upper level policy to the local circumstances (Jänicke, 2017). At the local level, capacities are understood and issues can be addressed accordingly (Jänicke, 2017; Smedby & Quitzau, 2016). In addition, local co-benefits can motivate sustainability related action, like climate action leading to local air quality improvements (Bollen et al., 2009).

The interplay between different governance levels, ranging from global to local is described as multilevel-governance, a concept originating from the description of policy processes in the EU (Stephenson, 2013). Vertical and horizontal relationships characterize multilevel-governance on each level, as for instance in climate governance (Jänicke, 2017). Multilevel-governance offers the opportunity to learn and experiment through local level action while best practices can be exchanged and up-scaled through vertical and horizontal relationships (Corfee-Morlot et al., 2009; Jänicke, 2017). City networks, like ICLEI (ICLEI, 2019a) or the C40 network of global mega cities (C40 Cities, 2020), are a good example for horizontal relationships between local level governments (Jänicke, 2017; Kern & Bulkeley, 2009).

One perspective on the purpose of public institutions like local governments is their role to ensure the provision of public goods and services (De Bruijn & Dicke, 2006). Public goods and services are publicly supported objectives, like social security, health or air quality (Ostrom & Ostrom, 1977). They are non-exclusive which means anyone can access them, and they contribute to the well-being of society as such (Ostrom & Ostrom, 1977). Nature (Hardin, 1968), as well as sustainable public infrastructures (van Gestel et al., 2008) can be considered a public good. Van Gestel et al. (2008) studied how local authorities manage public interests in DH infrastructure projects. They found a shared culture and interest was more important that contracts and legislation. De Bruijn and Dicke (2006) investigated how affordability, safety, and environmental protection are ensured in liberalized utility sectors. 'Hierarchical', 'market' and 'network' mechanisms are used in order to safeguard public values. These mechanisms are introduced as modes of governance later in this Chapter (3.3).

Scholars developed theoretical approaches how to assess WHR potentials within a city or region. One example are regional resource and energy flow analysis after the concept of Urban Metabolism (Prytula, 2011) that quantify inputs, outputs and storage of energy, water, nutrients, materials and waste in an urban region in analogy to the metabolism of organisms (Wolman, 1965). However, according to Kennedy et al. (2011), this theoretical approach never got established in the practice of urban planning.

A theoretical application of Urban Metabolism in urban energy planning, is the Urban Harvest Approach presented by Leduc & Van Kann (2013). It suggests synergies and resource exchange between different urban functions, and to systematically harvest local renewable and residual resources to close resource flows. Urban energy synergies can increase the productivity of urban areas and have social and environmental benefits (Leduc & Van Kann, 2013).

Similarly, Tillie (2018) presents urban planning principles to create synergies between different urban functions. Those principles have been applied in Rotterdam's urban energy planning strategy, the Rotterdam Energy Approach and Planning (REAP) (Tillie et al., 2009). On different geographical levels, building, neighborhood, district, and city, three steps of energy planning are suggested. The first step is reducing energy demand, the second step exchanging waste energy flows between urban functions, and the third step promoting RE solutions for the remaining demand (see Figure 5).

| | *Demand reduction* | *Waste heat recovery* | *Sustainable generation* |
|---|---|---|---|
| **City** | **Avoid** energy demand by urban measures | Connect to **communal energy grid** | Generate **renewable energy** centrally |
| **District** | **Avoid** energy demand by urban measures | **Exchange and balance,** or **cascade energy** on the district scale | Generate **renewable energy** on the district level |
| **Neighbourhood** | **Avoid** energy demand by environmental measures | **Exchange and balance,** or **cascade energy** on the neighbourhood scale | Generate **renewable energy** on the neighbourhood level |
| **Building** | **Avoid** energy demand by architectural measures | **Re-use** waste energy on the building scale | Generate **renewable energy** on the building level |

*Figure 5 Rotterdam Energy Approach and Planning*

*Source: adapted after Tillie et al. (2009)*

Lenhart et al. (2015) studied the role local authorities had in developing the energy planning strategy REAP. This case study is the sole study identified addressing the governance of WHR, under the term 'urban symbiosis[1]', specifically. Lenhart et al. (2015) found, the city of Rotterdam initiated dialogues between multiple stakeholders, by hosting workshops and mediating between parties.

In sum, research on local governments supporting WHR is limited to date. Some technical theoretical urban energy planning approaches were identified. The case study by Lenhart et al. (2015) is limited to the planning phase of REAP, it states Rotterdam stepped back in the implementation phase, when WHR projects were actually realized .

In accordance with the scope of the study and in light of the fact DH systems indirectly support WHR through providing necessary infrastructures, the review was extended to prior research on local governments supporting DH. A publication by the United Nations Environment Program (UNEP, 2015) describes different roles local governments can take in order to promote the development of DH systems.

[1] Urban Symbiosis examines material recycling in urban settings, how exchange of urban resources (e.g. water and energy) can close linear consumptions (van Berkel et al., 2009). The concept is closely related to the term 'Industrial Symbiosis' describing collaborations between traditionally separate industries, through exchange of energy, water, by-products, services or knowledge to achieve competitive advantages and/or sustainability improvements (Chertow, 2000).

They can support DH as

- *Planner and regulator* (through developing energy strategies, visions, goals or targets);
- *Facilitator* (through financial or fiscal incentives, investing in city assets or pilot projects);
- *Provider and promoter* (through self-governance, tariffs, acting as a large consumer);
- *Coordinator and advocate* (through providing or generating data; facilitating partnerships);
- *Through awareness raising and outreach* (for DH, locally and on upper governance levels).

Looking at local governance more broadly, several studies were identified that analyze how local governments manage public interests and steer energy transitions. Smedby & Quitzau (2016) for instance studied the governance of energy efficiency in the building sector. Bulkeley & Kern, (2006) studied local climate governance in energy, transport, waste and land use more broadly. Bulkeley & Kern (2006) describe different capacities local governments utilize for steering transitions: authority, ability to self-governing, delivering services and resources, and facilitating, coordinating and encouraging actions through partnerships. Those capacities explain why local governments are able to take the aforementioned roles to support DH:

- *Authority* allows planning and regulation;
- *Ability to self-governance* allows the provision and promotion (of a technology);
- *Ability to deliver services and resources* allows the facilitation of markets and knowledge creation;
- *Ability to facilitate, coordinate and encourage actions through partnerships* allows coordination and advocacy, awareness raising and outreach (on the behalf of a solution).

In addition to different roles local governments take, different 'steering modes' as logic through which governance is executed are described in prior research. The concept of hierarchal, network and market governance, as introduced in the following chapter, was used by Newell et al. (2012) in an extensive review of multi-actor environmental governance. Pahl-Wostl (2019) used it to compare sustainable water management between countries. Their study is relatable to energy governance, as water governance is similarly concerned with the provision of a public good. In addition, hierarchal, network and market governance is an established way to differentiate governance styles of environmental policy in the EU (Bouwma et al., 2015) which underlines the relevance of the concept especially in the European context. The following subchapter introduces background and difference between the three ideal-type modes of governance, hierarchal, network and market governance.

## 3.3 Ideal-type Governance Modes

There has been an intense debate about the meaning of governance and modes of governance in recent years (Kooiman, 2003). Some scholars argue governance concerns all processes of coordinating individuals, formal or informal organizations (Bevir, 2013). However, most contributions share the focus on the relationship between state intervention and social autonomy (Treib et al., 2007). Combining definitions by Hufty (2011) and Koch & Buser, (2006) governance is 'the steering and coordination of interdependent actors to address a collective problem that leads to the creation, reinforcement, or reproduction of social norms and institutions'. 'Public governance' is concerned with public goods and services, in order to constrain, prescribe, and enable their provision (Hill et al., 2005).

Modes of governance refer to a certain logic and form through which governance is realized (Lange et al., 2013). 'Hierarchies', 'networks' and 'markets' refer to different types of socio-economic order (Thompson, 1991). Accordingly, hierarchal, network and market governance are logics through which the coordination of social actors is interpreted and executed (Pahl-Wostl, 2015).

There are several origins of literature on governance modes. One is the observation that 'new' types of governance evolved in addition to the nation state which has been seen as a critique on hierarchical governance styles (Kooiman, 2003; Rhodes, 1997; Stoker, 1998). Another, the distinction between 'markets' and 'hierarchies' for the coordination of production systems and organizations in economics (Coase, 1937; Hayek, 1944).

In public governance, a reason for the existence of different modes of governance is the trend of liberalization of public services (Héritier & Schmidt, 2000). According to Bulkeley & Kern, (2006) this was triggered by difficulties municipalities had providing services and enforce regulations. It is discussed controversially, if a shift from hierarchical governance towards market and network governance really happened (Frederickson et al., 2003). Hill & Lynn (2005) demonstrate the preservation of hierarchical governance by reviewing 800 studies. They found constitutional authority simply has changed towards new administrative forms, novel actors and an increasing number of non-state actors in public governance. Lange et al. (2013) highlight the coexistence of different modes of governance in reality.

The fundamental logics behind the three ideal-types, hierarchical, network and market governance are explained in the following.

### 3.3.1 Hierarchical Governance

Hierarchical governance is in essence about top-down steering (van Buuren & Eshuis, 2010). It appears as authority with super ordination and subordination, as rule-governed regulatory coordination and administration with bureaucratic measures (Thompson, 2003), and is strongly related to the idea of a nation state where a democratic government uses its authority for intervening in society and markets (Meuleman, 2008).

As hierarchical organization implies a top-down command structure, it requires some form of 'objective in sight' (Thompson, 2003). Political decision define objectives that is followed up by directive action (Thompson, 2003). Control is executed through rule making, standard setting, the issuing of orders or directives, supervision, monitoring and auditing (Thompson, 2003). Traditionally, environmental policy has been focusing on hierarchical forms of governance (Bouwma et al., 2015). The characterizing top-down norms with prohibitive character to alter human behavior, stayed dominant over a long time (Backes et al., 2006).

### 3.3.2 Network Governance

Network governance is characterised by the operational autonomy and interdependence of actors involved (Sørensen & Torfing, 2009). Network governance addresses problems that are commonly felt by the actors involved. However, goal consensus can be a challenging aspect (Khan, 2013) and thus involve 'conflict-ridden negotiations' (Sørensen & Torfing, 2009). As the relationship between actors in governance networks are interdependent, their organization is based on trust and reciprocity (Pahl-Wostl, 2019). Trust between agents might be based on informal 'contracts' of rules and norms, however, formal and legally binding contracts can exist too (Thompson, 2003).

Network governance can blur the boundary between state and society (Kooiman, 1993), as power is dispersed and linked to the centrality of individual actors (Pahl-Wostl, 2019). Nevertheless, network governance does not describe the absence of hierarchy. Rather, it is "policy making in the shadow of hierarchy (Sørensen & Torfing, 2009, p. 236)". Authorities can shape the regulative, normative, cognitive and imaginary framework governance networks which is referred to as 'meta-governance' (Sørensen & Torfing, 2009).

### 3.3.3 Market Governance

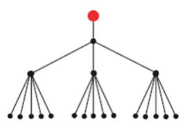
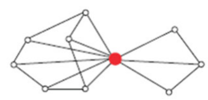
Markets create economic order without any conscious organizing center as they rely on decentralized decision-making of self-interested economic agents (Thompson, 2003). Economic order is created by the 'invisible hand' of the market (Williamson, 1985), based on the price mechanism and contractual arrangements within a competitive process (Thompson, 2003).

The role of public authorities in market governance is to ensure functioning of imperfect markets (van Buuren & Eshuis, 2010). According to neoclassical theory, state intervention should only focus on ensuring market access and on preventing monopolies that threaten competition (Thompson, 2003). Present environmental policy aims to define and encounter monetary values for the environment that currently are disregarded by the market which is achieved by taxes and financial incentives (Bouwma et al., 2015).

In the 1980ies and 1990ies the idea emerged that governments should be organized like companies. This trend has been labeled as 'New Public Management' (Osborne & Gaebler, 1992). The public sector should be smaller, focused on efficiency, working with clear performance specifying budgets, and work in partnership with profit driven actors of the private sector (Pollitt, 2001). New Public Management in comparison with traditional governance aims to reduce the extent to which governments face and address the complexity of issues by their own action (Klijn, 2012).

To summarizes, the three different modes of governance, hierarchical, network and market governance differ in the logic through which governance is realized and actors are coordinated. Furthermore, they differ in their understanding of the role governments have, the origin of power, locus of authority, and respective modes of steering and resource mobilization which is summarized in Table 5.

*Table 5 Hierarchical, network and market governance: authority and steering*

| Mode | Hierarchical | Market | Network |
|---|---|---|---|
| **Role of the Government** | Government **rules society;** dependency of other actors on it | Government **delivers services** to society; independency of actors | Government is **partner in network society**; interdependency of actors |
| **Origin of power** | Position in formal hierarchy | Degree of wealth, market share | Centrality in network |
| **Locus of authority** |  |   |  |
| **Control** | Authority | Price | Culture and contracts |
| **Steering** | Command and control; imperatives, *ex-ante coordination* | Delegating, enabling; competition; *ex-post coordination* | Coaching and supporting; diplomacy, self-organized coordination |
| **Instruments of resource mobilization** | Engage actors with political power; tax; gov. budgets for financing | Engage actors with market power, investment | Mobilize broad stakeholder support; voluntary financing |

*Source: Own compilation after Pahl-Wostl (2015)*

Based on the ideal-types hierarchical, network and market governance, several governance frameworks have been developed (Arnouts et al., 2012; Lange et al., 2013; Pahl-Wostl, 2015; Treib et al., 2007). Taking into account prior research on local energy and transition governance, a suitable framework for this study, is developed within the next chapter. More specifically, the three ideal-type modes of governance are interlinked with the roles local governments can take in order to support DH suggested by UNEP (2015).

## 3.4 Governance Modes to Address Barriers to Waste Heat Recovery

Thus far in this chapter, different types of barriers to WHR have been described (Chapter 3.1); prior research on WHR-related governance revealed different roles local governments can take in order to support DH (Chapter 3.2); and the three ideal-types *hierarchical*, *network* and *market governance*, as a common framework to analyze governance instruments were introduced (Chapter 3.3).

Despite the roles identified in Chapter 3.2, namely *planner and regulator, facilitator, provider and promoter, coordinator and advocate* and the activity of *awareness raising and outreach* are described to facilitate DH-supportive and not WHR-supportive governance, they are assumed to be transferable for the following reasons. Firstly, WHR within the scope of this thesis is realized in DH. DH infrastructures thus indirectly support WHR. Secondly, both solutions are part of the same socio-technical system of urban heating systems. Actors, infrastructures, and legal frameworks are therefore expected to be closely related. And thirdly, as outlined before, the roles described by UNEP (2015) are rooted in general capacities local-level governments have (Bulkeley & Kern, 2006). Thus, they are expected to apply to local governance of WHR as well.

In Table 6, six different modes of governance are described that address barriers to WHR according to a specific logic and respective activities and instruments.

Through generating rules, legal frameworks and instruments, the governance mode of *Hierarchical Planning and Regulation*, can address a broad variety of barriers. At least in theory, legal frameworks and regulation, can compensate lacking market incentives through enforcing activities or investments. Similarly, a lack of knowledge on WHR technology, business models and policy options, can be addressed through mandated research, or separately acting actors can be forced to cooperate. The same variety of barriers that Hierarchical Planning and Regulation can address, can in theory be addressed by *Market Facilitation*. If market incentives are high enough, research, collaboration, and investments can be stimulated. The second governance mode, referring to a market logic, *Market Provision and Promotion,* differs from Market Facilitation in a way that the government itself becomes an active market agent. By acting like a large consumer, or supplier of waste heat, potentially enforced by self-governance or procurement rules, Market Provision and Promotion addresses a lack of demand or supply as barrier to WHR.

Three modes of governance can be described that underlie a network mode of governance and thus horizontal relationships between actors. They differ in which role, or capacities of the local government, are used to address barriers. Firstly, *Network Facilitation* through research and pilot project generates knowledge and thus can address a lack of knowledge on technology, business model and policy options. Secondly, *Network Coordination and Advocacy* through coordination, facilitating partnerships, and providing information, addresses barriers related to a lack of information or data, and separately acting actors. Thirdly, *Network Awareness Raising and Outreach* address the lack of awareness on technology; business model and policy options, for instance through lobbying for support at upper governance levels.

*Table 6* ***Analytical Framework****: Governance modes to address barriers to waste heat recovery*

| Mode of Governance | Logic | Instruments | Barriers to WHR |
|---|---|---|---|
| *Hierarchical Planning and Regulation* | Generating rules and legal frameworks | Goals, strategies, targets or regulative instruments | Lack of market incentives;<br>Lack of knowledge on technology, business model and policy options;<br>Lack of information and data; separately acting actors |
| *Market Facilitation* | Generating market incentives | Financial or fiscal incentives, investments in city assets | |
| *Market Provision and Promotion* | Creating demand or supply | Act like a large consumers, self-governance, procurement rules | Lack of demand or supply |
| *Network Facilitation* | Generating knowledge | Research and pilot projects | Lack of knowledge on technology; business model and policy options |
| *Network Coordination and Advocacy* | Coordinating | Facilitating partnerships, provision of information | Lack of information and data; separately acting actors |
| *Network Awareness Raising and Outreach* | Creating awareness | Lobbying for support at upper governance levels | Lack of knowledge and awareness on technology; business model and policy options |

*Source: Developed by the author based on literature review in Chapter 3.1, 3.2 and 3.3.*

In accordance with the framework presented, typical barriers to WHR, as presented in Chapter 3.1 are theoretically linked to the different governance approaches in the following.

To begin with, multiple barriers to WHR can be addressed by *Hierarchical Planning and Regulation* through the creation of legal frameworks. Examples are inertia, competition with alternative solutions, existing business models and planning horizons (see Table 7). These are economic, cognitive and institutional barriers.

*Table 7 Barriers addressed by Hierarchical Planning and Regulation*

| **Hierarchical Planning and Regulation** (through generating rules and legal frameworks) | |
|---|---|
| **Type of barrier** | **Barrier to WHR** |
| Institutional barriers | - Lack of institutionalized responsibilities and planning procedures (local government)<br>- Lack of mandate (local government)<br>- Lack of planning control in liberalized energy markets (local government)<br>- Short political planning horizon and changing political and financial climates (local government; national level policy maker)<br>- Lack of capacity and know-how for the implementation of projects (local government) |
| Market barriers | - Competition with existing business areas of primary waste heat provision (energy utilities)<br>- Competition with other heat sources (energy utilities)<br>- Competition with heat from other heat sources (customer) |

| | |
|---|---|
| Financial barriers | - High investment costs with long payback periods (energy utilities; investor)<br>- Short-term investments decisions, oftentimes not based on life cycle costs (waste heat provider)<br>- Lack of relevance or even disturbance through WHR (waste heat provider) |
| Knowledge barriers | - Limited knowledge on technology (energy utilities)<br>- Lack of best practices on how to distribute risks and benefits (energy utilities; waste heat provider)<br>- Lack of knowledge on policy options (local government) |
| Cognitive barriers | - Lack of standardized procedures or legal frameworks (Energy utilities) |

As outlined before, similar barriers that can be addressed by *Hierarchical Planning and Regulation* can be addressed by *Market Facilitation*. This is valid for financial and market barriers, knowledge and cognitive barriers (Table 8). It excludes institutional barriers to WHR, as local governments might not be able to influence jurisdiction by market incentives.

*Table 8 Barriers addressed by Market Facilitation*

| **Market Facilitation** (through market incentives) | |
|---|---|
| **Type of barrier** | **Barrier to WHR** |
| Market barriers | - Competition with existing business areas of primary waste heat provision (utilities)<br>- Competition with other heat sources (utilities)<br>- Competition with heat from other heat sources (customer) |
| Financial barriers | - High investment costs. long payback periods (utilities; investor)<br>- Short-term investments decisions, oftentimes not based on life cycle costs (heat provider)<br>- Lack of relevance or even disturbance through WHR (heat provider) |
| Knowledge barriers | - Limited knowledge on technology (utilities)<br>- Lack of best practices on how to distribute risks and benefits (utilities; heat provider)<br>- Lack of knowledge on policy options (local government) |
| Cognitive barriers | - Lack of standardized procedures or legal frameworks (utilities) |

Through generating demand or supply of waste heat, *Market Provision and Promotion* can address a lack of the same (Table 9). The lack of demand or supply of recovered heat was not explicitly mentioned as barrier to WHR project in literature, but rather is an obvious condition to projects, as demand without supply, or supply without demand, does not create a market.

*Table 9 Barriers addressed by Market Provision and Promotion*

| **Market Provision and Promotion** (through creating demand or supply) | |
|---|---|
| **Type of barrier** | **Barrier to WHR** |
| Market barrier | - Lack of demand or supply (not explicitly mentioned in literature, but obvious condition to WHR) |

*Network Facilitation* can address barriers to WHR that reflect knowledge gaps, such as lack of knowledge on technological solutions, business models or policy options. Through generating data on the local context, it also can address barriers, such as a lack of knowledge on available heat sources. In addition, knowledge, in form of experiences, can address cognitive barriers to WHR (Table 10).

*Table 10 Barriers addressed by Network Facilitation*

| **Network Facilitation** (through generating knowledge) | |
|---|---|
| **Type of barrier** | **Barrier to WHR** |
| Knowledge barriers | - Lack of awareness on heat source availability (local government)<br>- Limited knowledge and experience with technology (energy utilities)<br>- Lack of awareness on technological options (waste heat provider)<br>- Lack of best practices on how to distribute risks and benefits (energy utilities; waste heat provider)<br>- Lack of knowledge on policy options (local government) |
| Cognitive barriers | - Immaturity of technologies (customers) |

With *Network Coordination and Advocacy* local governments make use of their capacity to facilitate, coordinate and encourage actions through partnerships, or matching stakeholders and data. This allows to address cognitive and knowledge barriers to WHR that occur based on a lack of coordination (Table 11).

*Table 11 Barriers addressed by Network Coordination and Advocacy*

| **Network Coordination and Advocacy** (through coordination) | |
|---|---|
| **Type of barrier** | **Barrier to WHR** |
| Knowledge barrier | - Lack of capacity and know-how for the implementation of projects (local government)<br>- Lack of competence to initiate or implement projects (waste heat provider)<br>- Lack of awareness on heat source availability (local government)<br>- Limited knowledge and experience with technology (energy utilities)<br>- Lack of awareness on technological options (waste heat provider)<br>- Lack of best practices on how to distribute risks and benefits (energy utilities; waste heat provider)<br>- Lack of knowledge on policy options (local government) |
| Cognitive barrier | - Lack of best practices on how to distribute risks and benefits (energy utilities; waste heat provider) |

Lastly, through *Network Awareness Raising and Outreach* local governments can generate public and political awareness for WHR, locally and beyond. Barriers to WHR that occur based on a lack of public of political support at upper governance levels, such as cognitive, knowledge and institutional barriers to WHR thus can be addressed (Table 12).

*Table 12 Barriers addressed by Network Awareness Raising and Outreach*

| **Network Awareness Raising and Outreach** (through creating awareness) | |
|---|---|
| **Type of barrier** | **Barrier to WHR** |
| Institutional barriers | - Lack of mandate (Local government)<br>- Lack of planning control in liberalized energy markets (Local government)<br>- Short political planning horizon and changing political and financial climates (Local government; National policy maker) |
| Knowledge barrier | - Lack of awareness on technological options (waste heat provider)<br>- Lack of awareness on technological opportunities and policy options (National policy maker) |
| Cognitive barrier | - Lack of standardized procedures or legal frameworks (Energy utilities; waste heat provider) |

Summarizing, all barriers to WHR identified in literature can be linked to at least one of the six governance modes presented. Several barriers can even be addressed by multiple approaches. The lack of demand or supply was not explicitly stated as a barrier in literature, but fits the framework as an obvious condition to WHR. The framework seemed well suited to analyze municipal governance addressing barriers to WHR. Hence, it was used to guide data collection and analysis, as described in the next chapter.

# 4 Methods

## 4.1 Research Design

The core of this research is a multiple-case study. It consists of an in-depth analysis of WHR related governance in the case cities, Gothenburg, Turku and Rotterdam. In order to inform the actual case studies, a pre-step was taken. It consists of an exploratory review of WHR-supportive governance instruments mentioned in theory and practice and answers *RQ 1*. Analyzing WHR related governance in the case cities answers *RQ 2*.

Data collection in both research steps was guided by the analytical framework that was developed based on the literature review and is presented in Chapter 3.4. Results of the case studies were analyzed individually and then comparatively which is common for multiple-case studies (Yin, 2014). The replicability of learnings is discussed in order to draw conclusions that are transferrable to other context. Figure 6 summarizes this research design. Methodological choices for data collection and analysis in are outlined in the following.

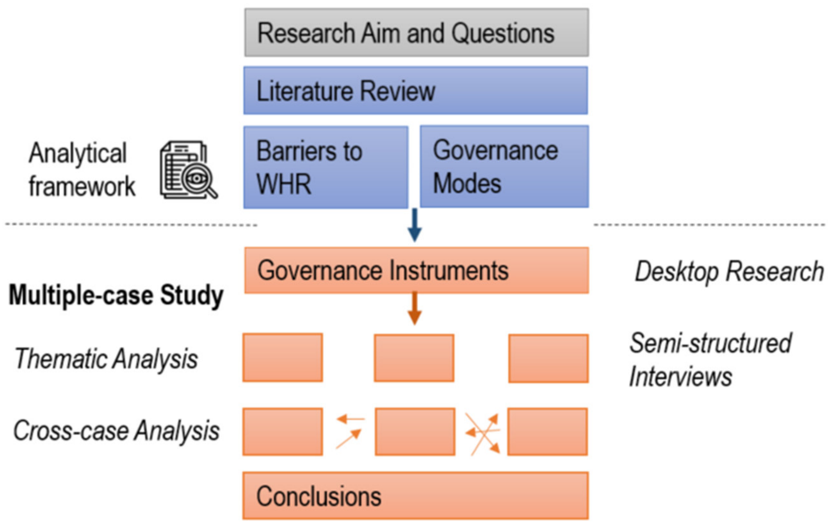



*Figure 6 Research Design (own illustration)*

### 4.1.1 Multiple-case Study

Case study research focusses on gathering empirical evidence from one or more analytical units in order to examine the research topic (Blaikie & Priest, 2019), most typically to answer "how and why" research questions. The subject of this thesis is a contemporary phenomenon for which case studies are typical (Yin, 2014). Case studies are suitable for observational research in real-world context which means the researcher does not modify the subject, which reflects the approach of this thesis (Yin, 2014).

According to Yin (2014), defining unit(s) of analysis, theoretical propositions to guide data collection, logic of linking the data to the propositions, and criteria for interpreting the findings, are especially important in case study's research design. Theoretical propositions to guide data collection and analysis are common in descriptive or explanatory case studies (Yin, 2014) and applies also to this study.

The unit of analysis in this thesis are local governments, including cities or regions. Sub-units of local governments, like different departments are disregarded, as organizational structures differ from city to city. The boundary of each unit of analysis are the geographical and organizational boundaries of each municipality chosen.

An amount of three cases was chosen, as evidence from multiple cases is considered to be more compelling and robust compared to single cases (Herriott & Firestone, 1983). Single case studies only are recommended when unusual or extreme cases are investigated (Yin, 2014). The ideal number of cases depends on the researcher's resources. Yin (2014) suggests a number of two to three cases when theory is straightforward and the issue does not demand a high degree of certainty.

### 4.1.2 Selection of the Cases

Three cities were selected for the case studies: Turku, Gothenburg and Rotterdam. Primary criterion for selecting the cases, was a successful implementation of a local WHR project under involvement of local authorities which was derived from grey literature and websites (Celsius, 2020b; UNEP, 2015). Cities with differing characteristics were selected in order to arrive at a diverse set of learnings. The cities differ in their size, time of experience with WHR, and ownership structure of the local heat market (Table 13). Such selection after the *logic of theoretical replication* (Yin 2014) is used to identify contrasting results that are expected for anticipated reasons. It differs from a logic of literal replications, used with a selection of cases that are expected to lead to similar results. In order to decrease the language barrier while collecting data, cities were selected where a good level of English was anticipated. All three cities selected are ICLEI members. This was a priority, however, it was useful because ICLEI could provide their network which made facilitate the process of getting access to relevant informants.

*Table 13 Case cities: waste heat recovery projects and ownership structure*

| City | Population | WHR projects | Ownership of DH |
|---|---|---|---|
| **Gothenburg** | 570.000 | • WHR from St1 (former Shell) **refinery**, since 1980<br>• WHR from Preem **refinery**, since 1998<br>• WHR from sewage water, since 1983/1985 | **Municipal** energy company, monopoly |
| **Turku** | 190.000 | • WHR from sewage water, since 2009<br>• Pilot project two-way LTDH (65 °C) in city development district Skanssi<br>- Currently assessed: WHR from Neste **refinery** in Naatali | **Municipal** energy company, monopoly |
| **Rotterdam** | 650.000 | • WHR from Shell refinery, since 2018<br>- Currently assessed: WHR from **data center** | Several energy companies, **public** and **private** |

*Sources: see full table in Appendix 3*

## 4.2 Data Collection and Analysis

### 4.2.1 Desktop Research

Academic and grey literature, like policy documents, handbooks by governmental and non-governmental organizations (secondary data), was reviewed in order to answer RQ 1. The focus was on identifying WHR related governance instruments applied in practice, however, some theoretical examples were included too. The results, presented in Chapter 5 served as a preparation and benchmarking for the actual case studies. For this reason, it is exemplary and does not claim completeness. A consultation with professionals in the field at ICLEI showed that no major WHR pilot projects were missing.

Documented information on the case cities could only be analyzed to limited extent due to language barriers. It was limited to few policy documents that were available in English or translated with translation software, after respondents highlighted their importance. These documents included the city climate strategies of Turku (Turku City Council, 2018) and Gothenburg (City of Gothenburg, 2014), and the resilience strategy of Rotterdam (Gemeente Rotterdam, 2018).

### 4.2.2 Semi-structured Interviews

Data collection for the case studies, to answer *RQ 2* mostly relied on interviews which is one of the most important methods in case study research (Yin, 2014).

The interviewees were selected from differing stakeholder groups, depending on actors involved in WHR in the case cities. The initial aim, to speak with waste heat provider (industry), distributors (DH companies), consumers and regulators (local authorities), was revised due to issues of responsiveness. Thus, data collection relied on 'central actors', like representatives of city authorities and energy companies. In addition, two researchers and one politician were interviewed (see Figure 7). Interviewees were selected from publically available information on webpages and the 'snowballing' principle (Blaikie & Priest, 2019. In the case of Turku, contacts were identified through project partners. The direct connection to stakeholders in Tuku enabled a more in-depth data collection compared to the other cases. This was not seen as a threat in data analysis. In total, 12 interviews per Skype or telephone were conducted for the case study. In addition, two interviews with a representative of the city of Lund in Sweden and Lund's municipal energy company were conducted where a large-scale LTDH including WHR currently is constructed. Information derived from these additional interviews was used in the discussion. Further information on the interviews is provided in Appendix 1.

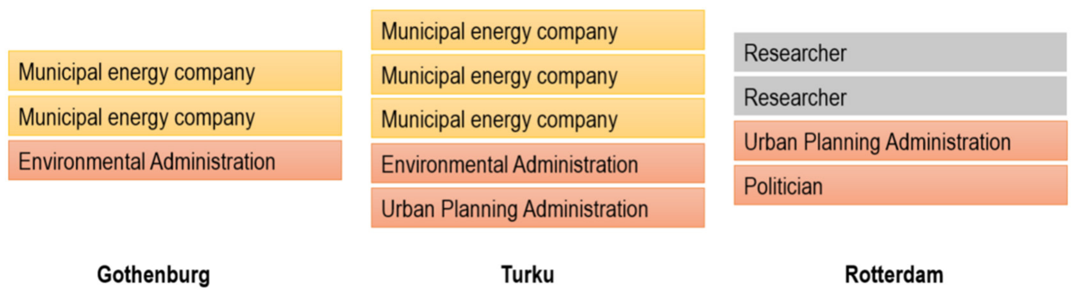



*Figure 7 Summery of interviewees by stakeholder group (own illustration)*

All interviews were semi-structured. This allowed for having a natural conversation while following the research agenda. According to Yin (2014) the agenda in case study interviews is always two-fold: firstly satisfying the needs of the logic of inquiry while secondly keeping 'friendly' and 'nonthreatening' questions to not bias the interviewee and allow for fresh commentary. The interview guide based on the analytical framework is provided in Appendix 5. Probes were only used if the breadth of questions seemed misunderstood. The focus of individual interviews was adopted to the interviewee's area of expertise. Flexibility when the exact perspective and level of knowledge of informants is unknown is an another general advantage of semi-structured interviews (Kvale & Brinkmann, 2009).

All interviews were recorded. The interviews were not fully transcribed for the two following reasons. Firstly, most of the information gathered is factual knowledge with an emphasis on what has been said rather than how. Secondly, information delivered in a nested way, arising from the fact that most respondents as well as the author are not native in English. Data from the interviews was summarized as bullet points in *interview protocols* which were send out to respondents in order to allow for further commentary.

### 4.2.3 Thematic and Cross-case Analysis

A *Thematic Analysis* of the interview data was conducted. It describes a systematic way of identifying patterns of common meaning across data sets (Schreier, 2012) that in contrast to a Content Analysis focuses on what has been said not on how often (Schreier, 2012). Accordingly, all interview protocols were coded supported by coding-software. Initially, codes were based on categories of the analytical framework. While coding, they were dynamically developed. The full coding structure is provided in Appendix 2.

In a first step, characteristics of each case were analyzed separately. The consistency of different data sources was checked for the need of further data-triangulation (*Individual Analysis*) (Lamnek, 2005). Guided by the sub-questions of *RQ 2* (Which governance instruments are applied? And why?) this involved the combination of a *descriptive* and *explanatory* case study approach (Yin, 2014) related to an *abductive* logic of inquiry that finds context specific explanations to the observed in theory (Blaikie & Priest, 2019).

In a second step, similarities and differences between the three cases were identified. In case study research with multiple cases, this is called c*ross-case synthesis* and serves as a meta-analysis of the cases (Yin, 2014). In order to formulate recommendations for other localities results were critically discussed towards their context before drawing conclusions.

# 5 Supportive Governance Instruments

This Chapter presents results of the first research step. It answers *RQ 1* by demonstrating examples of WHR-supportive governance instruments by local governments developed in theory and practice. The examples are derived from academic literature, handbooks, white papers and websites. Several examples were drawn from EU funded projects. A full list is provided in Appendix 4.

In accordance with the analytical framework (see Table 6 in Chapter 3.4), the presented instruments are linked to the six different governance modes *Hierarchical Planning and Regulation*, *Market Facilitation*, *Market Provision and Promotion*, *Network Facilitation*, *Network Coordination and Advocacy*, and *Network Awareness Raising and Outreach*

Several governance instruments that support WHR through energy related goals and strategies, and thus refer to *Hierarchical Planning and Regulation,* were identified. Cities that include recovered heat in their **energy goals** are Paris (City of Paris, 2018) and Gothenburg (City of Gothenburg, 2014) for instance. Both have the ambition to provide energy only from RE and recovered sources in the future (see Table 14). Further cities include WHR related activities in their **energy strategy**. Examples are Amsterdam with a district-by district approach to change heat sources and DH expansion objectives (City of Amsterdam, 2020), London with (waste) heat mapping and master planning (Greater London Authority, 2018), and Frankfurt implementing an 'Waste Heat Registry' (City of Frankfurt, 2019).

*Table 14 Energy goals and strategies including waste heat recovery*

| City | Energy goals and Strategies | Reference |
|---|---|---|
| Paris, France | Until 2050 **– 100% RE and recovered energy** (20% locally)<br>*Strategy includes*:<br>- Intensify energy recovery and exploitation<br>- Advocating for WHR (laundries, data centers, bakeries) | City of Paris (2018) |
| Gothenburg, Sweden | Until 2030 – **100 % RE and recovered energy in DH**<br>Until 2030 **– primary energy use** for electricity and heat ≤ 31 MWh/inhabitant | City of Gothenburg (2014) |
| Amsterdam, Netherlands | Until 2050 – all buildings **carbon neutral**<br>Until 2030 – all districts **natural-gas free**<br>*Strategy includes*:<br>- District-by-district approach<br>- Fuel switch to **higher use of waste heat**<br>- Looking to **capture waste heat from data centers**<br>- **expand DH network** to cover 50-60 % or the houses | City of Amsterdam (2020) |
| London, UK | Until 2050 – **Carbon neutral city**<br>*Strategy includes*:<br>- Utilize local and RE, like solar and **waste heat**<br>- **Heat mapping** and energy masterplans at district level | Greater London Authority (2018) |
| Frankfurt, Germany | Until 2050 – **lower GHG emissions 95 %** (compared to 1990)<br>*Strategy includes*:<br>- **Waste Heat Registry** | City of Frankfurt (2019) |

Formulating local energy action plans begins with identifying potentials as Krasatsenka et al. (2017) suggest. This can be done by spatial mapping of local heating and cooling demand and supply. Experiences from the STRATEGO project showed that simple maps already provide inspiration to related projects (Krasatsenka et al., 2017).

**Energy Potential Mapping** as presented by van den Dobbelsteen et al. (2018) captures energy demands and surpluses in combination with other spatial characteristics, like existing or planned infrastructure and topography. It links energy and urban planning (van den Dobbelsteen et al. 2018). An example of application is the mapping of waste heat potentials in Rotterdam by Broersma and Fremouw (2011). Several other cities have applied energy mapping too. Some of them provide Heat Maps as open source online (see Table 15).

*Table 15 Waste heat potential mappings*

| City | Type of Heat Map | Reference |
|---|---|---|
| Amsterdam, Netherlands | Open source | (Amsterdam Smart City, 2019) |
| London, UK | Open source, interactive | (CSE, 2020) |
| Vienna, Austria | Scientific Study | (Loibl et al., 2017) |
| Rotterdam, Netherlands | Scientific Study | (Broersma & Fremouw, 2011) |

Energy potential mapping software based on a Geographic Information System (GIS) and energy planning software targeting local and regional authorities amongst other, was developed by several EU funded research projects and is provided for free. In total, three such tools were identified.

- Hotmaps Project (2020)
- PLANHEAT (2019)
- THERMOS (2019)

With the same purpose, to systematically describe waste heat potentials, the city of Frankfurt (2019) introduced a **Waste Heat Register**. The cadaster records heat sources ranging from waste water, industry, and commerce, to large data-centers.

In order to decide whether heat utilization makes sense in the local context or not, a WHR feasibility calculator has been developed by CE-HEAT (2019a), and by Goumba et al. (2017). Both tools include economic and technical aspects. Making use of such tools, or making sure these tools reach the stakeholders that can use them in order to support WHR, refers to coordination in accordance with *Network Coordination and Advocacy*.

Further WHR-supportive governance instruments in accordance with *Hierarchical Planning and Regulation* were identified. They address DH in land use planning and building development. One example are requirements to assess DE opportunities when planning a building or district, as applied in Tokyo (UNEP, 2015). Another example are **Building Codes** favor DH connections in new building, as applied in Rotterdam, Hong Kong (UNEP, 2015) and Milan (UNEP, 2017).

Furthermore, **obligatory WHR**, an obligation to recover heat whenever generating it, is discussed in theory (UNEP, 2015; Wheatcroft et al., 2019). However, no application was identified.

In order to increase demand for recovered heat, cities can act as **large consumers** and procure waste heat for public facilities, like schools or hospitals (UNEP, 2015). The procurement may include **self-governance** in form of specific requirements on the energy mix purchased or, likewise, on the energy mix supplied by municipal energy companies (UNEP, 2015). Creating supply of or demand for waste heat is an example of *Market Provision and Promotion.*

Further examples for governance instruments referring to *Market Facilitation,* have been identified. They include for instance **low interest loans** for DH extensions, as applied in Paris, France (UNEP, 2017). In Amsterdam, **tax-free zones** for energy related pilot projects have been introduced (UNEP, 2015). Additionally, **tax breaks and investment subsidies** for WHR infrastructures (Wheatcroft et al., 2019) and tax breaks for waste heat feed-ins (Pehnt et al., 2011) have been suggested. Other examples are public infrastructure investments, **city assets**, that facilitate WHR, like the construction of a heat transmission line in Ashan, China (UNEP, 2015) or heat storage in Rotterdam (SCIS, 2020)**.**

There is a fine line between the aforementioned city assets for the purpose of facilitating WHR market and **pilot projects** for the purpose of generating WHR related knowledge. Facilitating WHR markets falls under the governance approach of *Market Facilitation.* Generating WHR related knowledge through pilot projects on the other hand refers to *Network Facilitation*. Within the scope of this thesis, several pilot projects were identified (Table 16). The research covered websites of research projects, cities, energy companies and technology providers. A handbook by the ReUseHeat project (Boye Petersen, 2017) and project websites (Celsius, 2020a; CE-HEAT, 2019c; ReUseHeat, 2017b) present additional pilot projects beyond the scope of this study, like for WHR in private DH systems or companies.

*Table 16 Waste heat recovery pilot projects*

| **Heat Source** | | **City** | **Reference** |
|---|---|---|---|
| **Sewage water** | | Tokyo, Japan | (UNEP, 2015) |
| | | Seattle, USA | (UNEP, 2015) |
| | | Vancouver, Canada | (UNEP, 2015) |
| | | Oslo, Norway | (UNEP, 2015) |
| | | Cologne, Germany | (Celsius, 2020e) |
| | | Gothenburg, Sweden | (Boye Petersen, 2017) |
| **Data Centre** | | Mäntsälä, Finland | (Sitra, 2019) |
| | | Brunswick, Germany | (ReUseHeat, 2017a) |
| | | Bergen, Norway | (GreenByte, 2020) |
| **Metro** | | Islington (London), UK | (Celsius, 2020f) |
| | | Berlin, Germany | (ReUseHeat, 2019b) |
| **Industry** | **Liquid gas** | Castelnuovo del Garda, Italy | (Celsius, 2020d) |
| | **Steel** | Ravne, Slovenia | (Waste Heat, 2019b) |
| | **Automotive** | Charleville-Mézières, France | (Dalkia, 2018) |
| | **Food** | Vienna, Austria | (Waste Heat, 2019a) |
| **LTDH** | | Brunnshög Lund, Sweden | (COOL DH, 2019) |
| | | Høje-Taastrup, Denmark | (COOL DH, 2019) |

Governance instruments referring to *Network Coordination and Advocacy* were identified in practice. One example that was mentioned in Chapter 3.2, is the development of REAP in Rotterdam. As described by Lenhart et al. (2015), Rotterdam's authorities initiated and coordinated **cross-sectoral dialogue** and learning around energy planning. Energy exchange between local industries, coordinated by local authorities through **facilitating partnerships** in Granollers, Spain (THERMOS, 2020) is another example.

Lastly, few examples of governance instruments referring to *Network Awareness Raising and Outreach* were identified. As project partners, city authorities are involved in several of EU funded projects mentioned. **Awareness raising** is stated as a central objective by several of these projects (Celsius, 2020a); (ReUseHeat, 2017c)). The city of Gothenburg, beyond that, has proactively initiated the CELSIUS project (Celsius, 2020a).

For each of the six governance modes, examples from theory and practice were presented. The most common were pilot projects. There are several free resources that support spatial mapping of waste heat sources. However, it remains unclear to which extant these are used by local authorities to date. Energy related goals and strategies are very common too, however, until now, they seldom explicitly mention WHR.

The following chapter analyzes WHR-supportive governance modes and instruments that were applied in the case cities.

# 6 Supportive Governance

This chapter answers *RQ 2* by analyzing results of the multiple-case study. It starts with providing an overview on each of the cases by outlining the extent to which WHR is realized in each of the cities. It then compares the cities' motivations to support WHR, and analyzes governance modes and instruments applied by the case cities to explicitly, or implicitly address barriers to WHR, sorted by the types of barriers *institutional, knowledge, financial, market* and *legal barriers.*

In Gothenburg, DH was introduced in 1953, and until the oil crisis in the 1970ies fueled by several large oil-fired boilers (Göteborg Energi, 2009). As a consequence to the crisis, WHR from the local refineries was discussed. In 1980 the first refinery was connected to the grid, followed by a second one in 1998 (Göteborg Energi, 2009). Today, DH accounts for approximately 90 % of all heating in the city (Göteborg Energi, 2020). Thus, it can be considered a mature DH system. WHR from the refineries supplies around 30 % of DH, the rest is covered by heat from a waste to energy and CHP plant (Göteborg Energi, 2018). The system is operated by the municipal energy company, Göteborg Energi, as a monopoly. The DH system in Gothenburg is one of the most price-efficient systems in Sweden (I 3). Of 266 DH systems in Sweden Göteborg has the 26$^{th}$ cheapest, being around 10 % under the average price (Nils Holgersson, 2019). The business model between waste heat providing refineries and Göteborg Energi was successful over the years and has been adopted by several other Swedish cities (I 1). Gothenburg's climate strategy, currently under revision, includes the goal to derive 'all DH by 2030, from RE, waste incineration and residual heat from industry' (City of Gothenburg, 2014). During data collection, interest of utilizing low-temperature heat sources in the future was stated (I 1). However, the main barrier currently is the upgrade needed to feed these into the existing high-temperature DH network. Since 1985, Gothenburg temporally recovers heat from sewage water by upgrading it through heat pumps. At present, there are some research and development activities concerning storage possibilities (I 2). Other than that, no activities around LTDH have been mentioned by the interviewees. The city is proactively creating awareness for the benefits of DH solutions. It initiated and coordinated the Celsius project, a joint research project on DH solutions by cities across Europe that is funded by the EU (Celsius, 2020a). Figure 8 provides an overview on the development of the system in Gothenburg. As it will become clear, when comparing with Figure 9 and Figure 10 for Turku and Rotterdam respectively, it illustrates the extent to which WHR-relevant aspect are developed in each case city.

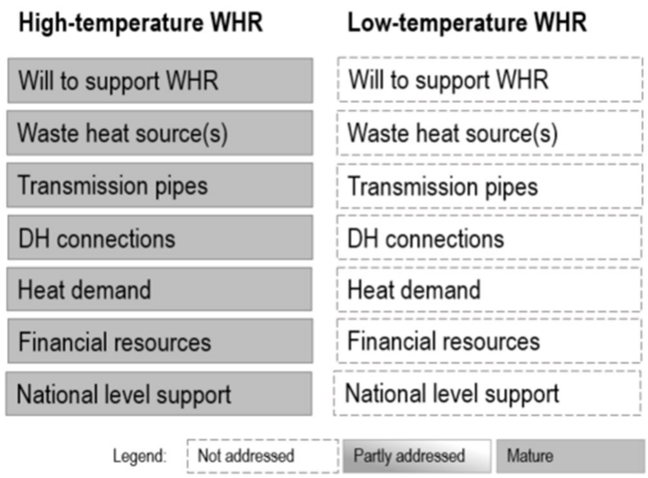



*Figure 8 Development stage of waste heat recovery in Gothenburg*

Turku, similar to Gothenburg, has with around 90 % of the buildings high coverage of DH (Turku Energia, 2020). Besides WHR from a printing machine, no WHR from high-temperature sources exists to date, but the possibility to recover heat from a refinery in spatial proximity is discussed since several years. The system is additionally fed by CHP, partly coal, partly biomass fueled and two smaller biomass plants (Turku Energia, 2020). Turku recovers DH and DC from sewage water through upgrading by heat pumps. The system is owned and operated by the municipal energy company Turku Energia. In the city development district Skanssi the municipality and Turku Energia aim to test a two-directional LTDH system with supply temperatures at around 65 ºC. The system is installed and first houses are connected. However, to date, the system is only used in the conventional, one-directional way (I 4). The end-customer are residential units that do not generate significant waste heat or cold (I 8), and no further low-temperature heat sources are connected so far.

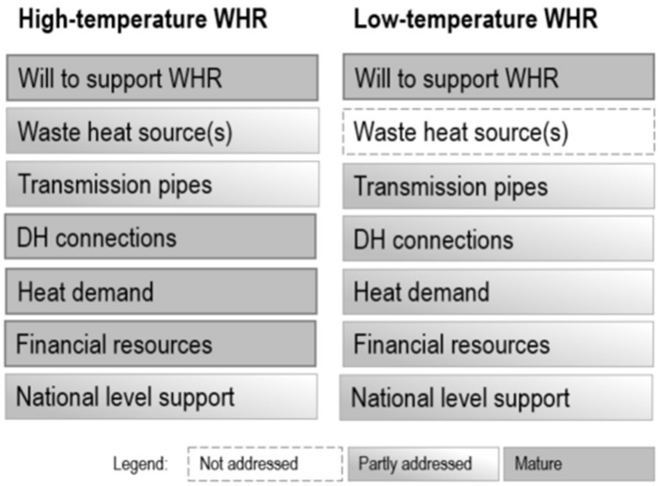



*Figure 9 Development stage of waste heat recovery in Turku*

For Rotterdam, data on the share of DH is not publically available, as private companies are selling DH to end-costumers (for more details see Appendix 3). Based on the capacity of the system (Warmtebedrijf Rotterdam, 2020), a coverage of around 15 % of Rotterdam's' households can be estimated. Currently, heat is mainly supplied by the waste incinerator which is located in the harbor area that bears high additional waste heat-potentials (Kreijkes, 2017). Most recently, in 2018, a refinery was connected to the network. As heat quantities exceed local DH demands at present, extensions to neighboring municipalities are discussed (I 10; I 12). Simultaneously, the city is working on increasing DH connections in existing local building stock. Replacing natural gas connections, which is the most common way of heating to date in Rotterdam, through DH, corresponds with a national level goal to phase out natural gas (I 11). Projects of heat exchange at building scale have been mentioned, however, information was not available in detail and would exceed the scope of this study. Otherwise, no low-temperature WHR has been mentioned by documents or the respondents.

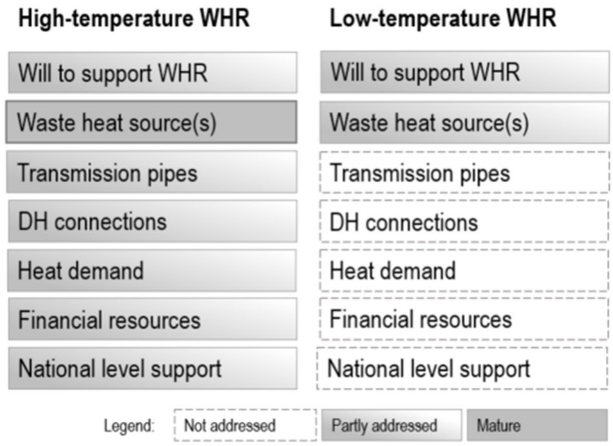



*Figure 10 Development stage of waste heat recovery in Rotterdam*

Summarizing, high- and low-temperature WHR is realized to different extent in the case cities. Different local aspects, including political will, accessible waste heat source(s), infrastructures, heat demand, are to different degree 'mature' in the case cities. As highlighted aspects can be interpreted as conditions to successful WHR, their maturity determines where current governance activities are focused on. In Gothenburg, high-temperature WHR is established while the step to develop a low-temperature WHR system is not started yet. In Turku, there is activity on developing both, high-temperature WHR and low-temperature WHR. In Rotterdam, the focus lies on increasing DH connections, in order to create demand for the available heat supplies.

The next Chapter presents results on the different motivations the case cities have to support WHR in the first place.

## 6.1 Motivations

Different aspects motivate WHR-supportive governance in the case cities. All three cities pursue low- or zero-carbon energy goals in order to contribute to climate change mitigation. In order to reach **carbon neutrality** until 2029, Turku aims to transform its heating sector that accounts for a large share of local emissions (I 4). The carbon neutrality goal mirrors national level ambitions (I 4, I 6, I 7). Increasing WHR is attractive for Turku, as other low-carbon heat sources, like biomass for bio-fueled CHP reaches local limits of supply (I 6, I 7). DH development in Rotterdam is likewise motivated by carbon neutrality goals, including the objective to phase out natural gas, as driven by the national government (I 11). Due to Rotterdam's geographic location, at low altitude and vulnerability to sea level rise, the discourse on climate adaptation is progressive, though highly political (I 10, I 12).

In Gothenburg, different reasons to invest in WHR occurred over time. Initially, the **independence from oil** was perceived as attractive when WHR was introduced in consequence of the oil crisis. Thereafter, **air quality** (since 1970) improvements built an argument for DH specifically, until climate change mitigation became the main argument (I 1). Similar to Turku and Rotterdam, oil phase out ambitions and, today, climate goals are mirrored by national level policy goals.

Ambitions to become a 'sustainability frontrunner' (Rotterdam, I 9), or to create a 'flagship project' (Turku, I 8) were mentioned in the case cities demonstrating motives of **city marketing.**

Representatives from Gothenburg additionally highlighted **economic factors** that incentivized WHR investments in the past. Replacing oil as a fuel was a measure to decrease dependency on global oil prices (I 1). Later, carbon dioxide and energy taxes introduced by the Swedish national government influenced investment decisions. Installing heat pumps to recover heat from sewage water in the 1980ies was a **business led** decision by Göteborg Energi (I 2). At the time, electricity prices were low, as Sweden invested in nuclear power. As electricity prices increased and fluctuate more since energy market liberalizations in the 1990ies, today WHR form sewage water is only used temporarily, when competitive with alternative production costs. DH in Gothenburg is one of Sweden's price-efficient systems, in terms of energy price for the consumer. For this reason, nobody ever really questioned it politically, according to interviewees (I 2, I 3).

## 6.2 Approaching Barriers

In the following, results on WHR-supportive governance in the case cities are presented. The chapter is structured after different types of barriers the governance instruments explicitly, or implicitly address. In accordance with the analytical framework (Chapter 3.4), the instruments are related to the different modes of governance *Hierarchical Planning and Regulation, Market Facilitation, Market Provision and Promotion, Network Facilitation, Network Coordination and Advocacy,* and *Network Awareness Raising and Outreach.*

### 6.2.1 Approaching Institutional Barriers

In Gothenburg and Turku, the city administration develops climate-related **energy goals** in tight collaboration with the municipal energy company. In Gothenburg, the Environmental Department develops environmental goals and is in charge of developing the climate strategy (I 3) while Göteborg Energi, as part of the municipality "follow[s] and support[s] their ambitions (I 2)". Göteborg Energi revises climate goals and strategy, as all other city departments and organizations (I 3). For renegotiating Gothenburg's new **climate strategy**, expected to be published in 2021, Göteborg Energi was strongly involved (I 1; I 3).

The process of developing energy goals was described a bit differently in Turku. The municipal energy company Turku Energia makes its own decisions (I 5). Likewise, TSE, the energy company co-owned by Turku and its neighboring municipalities, mentioned little interaction with the city (I 6). However, bigger municipal decisions, like the one on carbon neutrality, are binding for the whole organization, including the municipal energy companies (I 7). Turku Energia was involved in the development of the goals, mainly for estimating how realistic the ambitions regarding the energy system were (I 4). In both cities, it was perceived as important to align strategies between different departments and sub-units of the municipality (I 6, I 8).

In Gothenburg, the broader climate strategy is translated into more specific **energy plans** (I 3). Municipal energy planning is mandatory in Sweden since 1977 (Swedish Code of Statutes [SFS] 1997:439) which the city cooperates on with Göteborg Energi, the public housing, and the waste management company (I 3). Tapping their knowledge for energy planning is crucial according to the interviewee (I 3). A concern in relation to goal development are time constraints: "the politicians have not given the Environmental Agency much time to come up with new targets and that's always a risk (I 1)".

In the Netherlands, municipal energy plans are not mandated by the state. However, the city itself initiated the development of an energy vision, REAP, in the early 2000 which was possible due to sufficient human resources according to an interviewee (I 10). Smaller cities would hire an engineering firm or consultancy to do the same (I 10). Strong local leaders were perceived as strength in this process (I 9).

Energy goals and strategies were developed at different geographical scopes in the case cities. In Turku, for instance, a sustainability vision for the city development district of Skanssi exists (I 4). Developing energy strategies on district scale were perceived appropriate by experts in Rotterdam. Tailor-made solutions are needed as not every quarter is suitable for DH, influenced by existing building stock, energy infrastructures and local energy mixes (I 10). Accordingly, following the national level goal to phase out natural gas, Rotterdam recently assigned five districts for which alternatives to natural gas are assessed individually (I 11). The district are at different project stages. An external consultancy was commissioned by the city for comparing the cost-efficiency of different solutions. Until now, DH from waste incineration and additional WHR from different harbor industries, won over electric heating in all districts (I 11). In one of the districts, the potential to use waste heat from a data centre is evaluated (I 11).

An issue reported from Turku and Rotterdam were trade-offs between heat exchanges at building scale and utilizing waste heat or cold to further developing the district or city wide system. In Turku, a decision was made against exchanging heat between a public swimming pool and an ice arena directly, but rather deliver DH and DC to the city network (I 8). In Rotterdam, on the contrary, the planning approach REAP led to WHR projects at building scale but less to city wide heat exchanges (I 10).

In Gothenburg, Göteborg Energi is mandated to operate the DH network, owned by the city, through an **owner's directive** that is renewed every year (I 1). This directive includes environmental targets Göteborg Energi needs to adapt. At the moment, these targets demand a fossil free system until 2030 (I 1). An expansion of WHR is not explicitly pursued (I 1). Applying an '**energy hierarchy'** like the waste hierarchy used by the EU in order to prioritize energy investments was perceived as being valuable (I 1). Göteborg Energy already applies such a hierarchy, but more as a mind-set, not introduced officially yet (I 1). A paper that is expected soon to be adopted by the city council, includes such an hierarchy as an instruction to prioritize waste heat over RE when developing the system (I 1).

The enforcement mechanisms for energy goals and strategies differed between the case cities. After publishing the last climate strategy, Gothenburg's administration took a more passive role and left the operational responsibility to the stakeholders addressed (I 3). There was no legal enforcement, besides **monitoring** the performance of stakeholders like Göteborg Energi "to see if [they are] going in the right direction (I 3)". The city administration could only try to push them with 'soft measures' (I 3). With the new climate strategy, Gothenburg aims to take a more active role and support the implementation through an **advisory program** for stakeholders involved. How this program will look like concretely still is unclear (I 3). Similarly, in Turku, the Environmental Department reports on the implementation of the Climate Strategy to the city council at least once a year and at least twice a year to the city board. Then these parties can decide on adjustments (I 7).

Steering energy related decisions through the presented measures 'from above' can be seen as the governance mode of *Hierarchical Planning and Regulation.* An advisory program also could refer to *Network Coordination and Advocacy.* If direction is defined by the municipality, however, it more off reflects a collaborative form of *Hierarchical Planning and Regulation*. Table 17 provides an overview on governance instruments addressing institutional barriers to WHR.

*Table 17 Case cities' approach to institutional barriers*

| Mode | Governance Instruments |
|---|---|
| *Hierarchical Planning and Regulation* | • **WHR related goals** integrated in climate strategy, plan, or vision (all cases)<br>o Joint (Gothenburg) or independent (Turku) goal setting<br>o Different levels of detail and coordination between sectors<br>o Different scopes (city to district level strategy)<br>• **Municipal energy planning**<br>o National mandate for municipal energy planning (Gothenburg)<br>• **Goal enforcement**<br>o Soft measures and advisory program (Gothenburg in the future)<br>o Reporting and monitoring (Turku, Gothenburg)<br>• Politicians in board of municipal energy company<br>• **Owner's directive** to steer municipal energy company (Gothenburg)<br>o **Environmental targets** (e.g. 100% renewable and recovered heat in DH (currently discussed)<br>• **'Energy Hierarchy'** to prioritize waste heat over RE (Gothenburg in the future)<br>• Strengthen climate topic organizationally (Turku, Rotterdam)<br>o Create specific department<br>o Increase financial and human resources |

## 6.2.2 Approaching Knowledge as a Barrier

Identifying local waste heat potentials happens in different ways in the case cities. In Rotterdam, the city's waste heat potentials, including heat demands, were systematically mapped in 2011 (Broersma & Fremouw, 2011). The mapping was executed in close collaboration with academia, a researcher that has been a pioneer at this time in systematically combining urban and energy planning was involved (I 10). However, it remained unclear if the heat map is used by practitioners in Rotterdam at present. None of the other case cities reported mapping activities or any other systematic approach to identify local waste heat sources.

For a limited geographical area, like the district Rozenburg in Rotterdam, the available waste heat sources were perceived as quite straight forward (I 11). Assessing all WHR options for the entire city area was seen difficult and mainly limited by human resources by both energy company and city administration of Turku (I 5; I 7).

In Turku, identifying heat sources is done by Turku Energia in an unsystematic manner without any official strategy "whenever [they] have time" (I 5). The collaboration with local researchers has not been mentioned in the context of identifying heat sources specifically (I 5). Similarly in Gothenburg, the energy company is responsible for identifying heat sources (I 3). In this case, however, collaboration with the local university was mentioned (I 1, I 2).

Identifying potential waste heat sources refers to generating knowledge thus to the governance mode of *Network Facilitation*. Making this knowledge accessible to relevant actors, in addition, refers to *Network Coordination and Advocacy*. Table 18 provides an overview on governance instruments applied to identify waste heat potentials.

*Table 18 Case cities' approach to identify waste heat potentials*

| Mode | Governance Instruments |
|---|---|
| *Network Facilitation* | • Identify heat and cold sources on the go (Turku)<br>• Collaborations with academia (Gothenburg) |
| *Network Coordination and Advocacy* | • Energy mapping (Rotterdam)<br>• Combined urban and energy planning |

Additional knowledge barriers to WHR reported from the case cities were knowledge gaps on technical and business model solutions. The lack of technical knowledge, was not mentioned by respondents specifically. However, multiple research and development projects around finding technical solutions indicate a strong emphasis on finding technical solutions. More specifically, projects on heat storage solutions indicate there is a current knowledge barrier (I 1; I 4). Furthermore, the temperature difference between low-temperature heat sources and conventional DH systems were mentioned as a technical issue (I 1). Lack of experience (knowledge) on WHR business model, was an issue when WHR was firstly introduced in Gothenburg in the 1970ies (I 1). There were discrepancies between the industry and Göteborg Energi on value and pricing of the waste heat (I 1). There was no WHR business model established or tested in other locations at that time. The situation could be solved through the national government of Sweden stepping in as a mediator, putting pressure on the parties. Only if they agreed on a business model within a set timeframe, the state would support the project financially (I 1; I 2). As a consequence, the parties agreed on a business model[2] that is still used today and recommended by the Swedish District Heating Association for other WHR projects (I 1).

In Turku, a two-way LTDH should be tested as a **pilot project** from a technical, but also business model perspective (I 4). Based on an earlier feasibility study conducted by the urban planning department in collaboration with a large private company, the energy vision for the sustainable district 'Skanssi' was developed. It incused RE and waste heat trading between the buildings. Initially, Turku Energia was involved as an advisor, now they implement the system (I 8).A pilot project on heat storage is additionally conducted in Skanssi, another one in the city centre (I 8). Göteborg Energi recently conducted a feasibility study on storage technology in collaboration with a potential technology provider (I 2). Otherwise, in Gothenburg, as well as in Turku, collaboration with academia on these kinds of projects is common (I 1, I 2). In many city development and urban planning project, the city of Turku involves Turku Energia as an advisor. It was seen as an important success factor for WHR in Turku that the municipal energy company is proactive and constantly looking for new solutions (I 7).

Joint research by multiple energy companies was reported as a successful concept to generate knowledge from Sweden (I 2). In alliance with 35 other energy companies Göteborg Energi, has common resources for research. Projects are conducted in collaboration with external researchers and the Energy Agency of Sweden to increase the scope of their results (I 2). Similar benefits of

[2] **Value** of the waste heat in this model is the average between the value for the industry (0) and the value for the DH company which is based on the marginal cost for alternative heat generation in the system. - For instance, if the alternative heat generation are wood pallets at 3€ct/kWh, the value of the waste heat is 1.5€ct/kWh. The price is determined by a price floor and sealing negotiated based on this value and gets renegotiated regularly. (I 1)

collaboration and knowledge exchange between energy companies were reported from Finland (I 4).

Gothenburg and Rotterdam both collaborated with other cities on innovative waste heat sources and technologies in the EU funded Celsius project. A strength of this project was that each city participated with a representative of the city authorities, an energy company and an academic institution (I 10).

City networks were mentioned by the interviewees as a valuable platform to exchange experiences (I 1; I 4; I 9). Not only experiences on technical aspects, like focused by the Celsius project, but also on non-technical aspects, like Rotterdam's urban energy planning approach were shared in city networks (I 9). Best-practices on phasing out natural gas on district level are shared between Dutch municipalities (I 11)(Platform31, n.d.). Sharing experiences addresses knowledge, but also cognitive barriers to WHR. If another city was able to implement something, there is higher confidence to achieve the same by replicators (I 9). Furthermore, exchange on common challenges increases solidarity between cities (I 9). The scope of city networks mentioned by the interviewees reached from global networks like ICLEI or C40 to networks at national level.

In sum, there was an emphasis on technological aspects when talking about present knowledge related barriers to WHR. In Gothenburg and Turku, these are addressed by research and development activities within the municipal energy companies in collaboration with local academia, technology providers or other energy companies. Research and pilot projects that are conducted by the city or municipal energy companies reflect the governance mode of *Network Facilitation*. Sharing experiences between cities as an additional way to overcome barriers to WHR was mentioned by all case cities. Coordination of knowledge with external actors reflects the governance mode of a *Network Coordination and Advocacy.* Table 19 gives an overview on governance instruments applied to identify waste heat potentials.

*Table 19 Case cities' approach to obtain knowledge on technology and business models*

| Mode | Governance Instruments |
|---|---|
| *Network Facilitation* | • Research projects in collaborations with academia, technology provider (Gothenburg)<br>• Research and development in collaboration in with other energy companies (Gothenburg, Turku)<br>• Pilot projects, e.g. storage technology, two-way DH (Turku) |
| *Network Coordination and Advocacy* | • Collaboration and knowledge exchange with other cities (all cases) e.g. Celsius project |

### 6.2.3 Approaching Demand as a Barrier

In order to create a business case for WHR in DH, demand for DH is needed. The municipalities of Gothenburg and Turku purchase DH for municipal buildings. Large municipal facilities, like schools and hospitals are important DH customers (I 1; I 4). Additional ways to stimulate heat demands were described. The collaboration with between DH and public housing companies was mentioned as a success factor for DH in all three cases (I 1; I 7; I 11).

In Rozenburg, a part of Rotterdam, for instance, the city currently prepares a tendering process, open for companies willing to build and operate an extension of the DH network. The business case became more attractive to energy companies when the local social housing company, which owns 50% of the buildings in the area, agreed to purchase heat in the future (I 11). Similarly, when DH was developed in Gothenburg initially, the cooperation with public housing companies was crucial for ensuring demand (I 1). Likewise in Turku, 10 % of all buildings belong to the public housing company and are mostly connected to DH (I 7). The long-term planning horizon of public and student housing foundations was perceived as an advantage compared to collaborating with private actors (I 7). Creating demand as a large customer or through public housing companies reflects the governance mode of *Market Provision and Promotion*. Stimulating partnerships and heat demand from other, private actors can be assigned to *Network Coordination and Advocacy*.

The challenges faced when increasing DH demand by connecting new dwellings differed much between new and existing buildings. Connecting existing buildings can require large and expensive interventions.The city of Rotterdam intends to connect existing buildings in order to increase DH demand, because not much new housing is built (I 11). Especially older houses are expensive to connect. This is caused by a characteristic of Dutch houses to be heated by domestic boilers in the attic. Converting heating installations implies large interventions on the house, as DH is delivered underground. Investments between 10.000 and 15.000 € and long pay pack periods make a conversion not attractive for home owners (I 11). In Heindijk, one of the districts that currently phases-out natural gas, Rotterdam supported the conversion of houses financially. Firstly, the city payed for DH transmission pipes. Secondly, home owners received **zero-interest loans** for all investments on their houses up until 1. 500 €. Everything above was payed for by the city (I 11). National level subsidies supporting natural gas phase outs on district level applied (I 11) the extent to which they could cover the cost by the city remained unclear. The financial incentives Rotterdam applied in this case refers to *Market Facilitation*. It was not the only instrument applied in this case. The communication strategy with the home owners played a crucial role.

Firstly, a letter was sent out to inform about the project. Then, a small team of city representatives, including the project leaders, went from door to door (approximately 145 houses). In **personal dialogues** the aim of the project and aforementioned possibilities of financial support were communicated. The city's Social Department accompanied the dialogues in order to facilitate additional discussions on social or financial concerns. The interviewee reflected that it was a good opportunity to learn how to communicate with the local citizens in a direct manner (I 11). The measure was successful. When sufficient home owners agreed on converting their houses, a second letter was sent out, communicating the success. As a response, even more homer owners decided to connect. Communicating with private home owners in order to increase awareness for possible DH connections reflects *Network Coordination and Advocacy*.

DH connections in new buildings imply less technical issues. However, DH competes still with other technologies, like geothermal heat pumps in Turku (I 4; I 8), or air to air heat pumps in Gothenburg (I 1). Concerning the stimulation of DH connections through mandates, legal barriers were highlighted by several respondents. Due to rules of free market competition, DH connections cannot be mandatory in the EU.

More specifically, demanding DH purchases are not allowed as the case of Rotterdam shows. In Rotterdam, DH connections are mandatory for new buildings. However, this excludes the obligation to buy heat (I 10). The impact of this regulation was seen critical by a respondent, as some large-scale buildings in Rotterdam now have DH connections, but are not buying any heat (I 10).

In order to at least not dis favor DH over other heating solutions in new buildings, Gothenburg adopted national level building codes to **local building codes** approximately two years ago (I 1). The building codes reflect minimum requirements on the overall energy performance of new buildings. Trough assessing the energy performance based on used energy and not purchased energy, the national version systematically favors heat pumps over DH (I 1). Gothenburg's 'technology neutral' building codes are perceived as successful by the interviewee as most DH offers by Göteborg Energi were accepted lately (I 1). The requirements only apply to development projects on municipal land (I 1).

In order to achieve DH connections in the district of Skanssi, the city of Turku worked with a bidding process and building requirements. When municipal land was sold to property developers in a bidding process, **obligatory requirements** on the energy system were included, like to share waste heat wherever economically feasible. In addition, bidders could make **voluntary commitments** in order to receive extra points. Those voluntary aspects were provided from a list, one example, the utilization of recovered heat from ventilation systems for floor heating or to unfreeze pavement in winter (I 8). In general, energy systems fully based on RE were favored (I 4). The municipality's decision on who buys the land then was based on points added up for voluntary commitments and the price offered (I 8). According to an interviewee the described process helped to balance financial interests and sustainability ambitions of the city (I 8). The combination of firm requirements and voluntary aspects left flexibility to the construction companies, if they had own criteria already (I 8). The formulation of building requirements and voluntary commitments in Turku was supported by an external consultant in exchange with the city of Helsinki that applied similar codes in a district development project (I 8). Close collaboration with the building permit department was perceived as crucial, as this department finally checks the compliance of projects (I 8).

Not all land sold in Skanssi was owned by the municipality and therefore could go through the municipality' s bidding process For private land, **land use agreements** were used in order to apply similar conditions (I 8). Traditionally, an agreement between the land owner and the city specifies how costs for developing a property are divided. In this contract, the city of Turku included the same building requirements like described above.

Despite the requirement to exchange waste heat in Skanssi, until now the DH system is only operated in a conventional, one-way direction (I 8). The construction companies were open to test new technologies, however, time constraints interrupted the development process and a tentative solution was chosen. In addition, no large amounts of waste heat occur in the area to date, as it mainly consists of apartment buildings. In order to allow two-way heat exchange in the future, city and construction companies agreed to include extra space in the basement. This space can be used whenever heat feed-ins from waste heat or geothermal heat pumps shall be implemented. A similar agreement was made concerning future solar collectors.

The governance instruments presented so far include legal and voluntary building requirements, mandating or steering DH connections in order to stimulate demand for DH. Through their directive nature, they can be assigned to the governance mode of *Hierarchical Planning and Regulation.*

As a barrier to DH demand, a lack of public awareness for the sustainability of DH was mentioned (I 4). According to an interviewee, most (public) energy companies are not used to market their product (I 4). In order to be competitive, however, "[they] need to stand up from their desk and go out to talk to the people (I 4)". Increased dialogue and collaboration refers here to offering customized solutions and services instead of 'only' selling heat. Turku Energia for instance, is increasingly perceived locally as a provider of services (I 4, I 7).

Construction companies in Skanssi were motivated by the perceived marketing value of sustainable heating systems, when collaborating with Turku Energia on two-way DH solutions (I 8). Contrasting experiences were reported from Rotterdam where building developers were not convinced future tenants would pay the extra cost for systems that facilitate heat exchanges at building scale (I 9). Collaboratively developing WHR solutions in this context reflects the governance mode of *Network Facilitation*. Table 20 provides an overview on governance instruments applied to address a lack of demand and DH connections.

*Table 20 Case cities' approach to address demand as a barrier*

| Mode | Governance Instruments |
|---|---|
| *Market Provision and Promotion* | • Selling waste heat to end-customers (Turku, Gothenburg)<br>• Buying waste heat as an end-customer (Gothenburg)<br>• Market DH, sell service and advice (Tuku, Gothenburg,) |
| *Network Coordination and Advocacy* | • Collaborations with local (public) housing companies to create demand (Gothenburg, Turku)<br>• Personal dialogues with home owners to discuss possibility to connect to DH (Rotterdam) |
| *Market Facilitation* | • Zero-interest loans and subsidies to convert houses to DH (Rotterdam) |
| *Hierarchical Planning and Regulation* | • Self-governance<br>o DH in municipal buildings (Gothenburg)<br>• Building Codes (for buildings on municipal land)<br>o favoring or not dis favoring DH (Gothenburg, Turku, Rotterdam)<br>• Mandatory DH connections (without obligation to purchase) (Rotterdam)<br>• Bidding processes and tendering<br>o favoring WHR solutions (Turku)<br>• Land use requirements (for buildings on private land) (Turku)<br>• Limitation: enforcing DH not possible due to the rules of market competition in liberalized market. |
| *Network Facilitation* | • Joint development between energy and construction company (Turku) |

### 6.2.4 Approaching Financial Barriers

Several economic barriers hindered WHR projects in the case cities. Investment costs for WHR from a refinery close to Turku was found to be too costly ten years ago, but gets reassessed today (I 7). Building transmission pipes for WHR from the refineries in Gothenburg were only possible due to the support of the state (I 1). It was perceived as easier to make these long-term investments by municipal energy companies than by private companies (I 2).

When WHR from the harbor area was discussed in Rotterdam neither the local private DH companies were willing to invest, nor the industry (I 10). Rotterdam responded by founding the

'Heat Company', Warmtebedrijf, (98% city owned) in order to build and operate the transmission pipes. Selling heat to end customers, however, remained a responsibility of the private energy companies. The city supported the construction of the pipes with a municipal investment of 100-150 Mio €, motivated by the vision of a sustainable energy transition (I 12). At present, heat transmission is limited to heat from the waste incinerator, however, further waste heat from the harbor area can be accessed in the future (I 11).

Currently, issues of unfavorable contracting between Warmtebedrijf and the main heat provider, a waste incineration plant that was sold by the city some years ago, become visible (I 12). The contract requires Warmtebedrijf to buy the incinerator's excess heat until 2049. In estimation of the respondent, the heat volume Warmtebedrijf thus is required to purchase exceeds the city's DH demand (I 12). This puts Warmtebedrijf as a trader of heat in an unfavorable position. In addition, the price set in the contract does not reflect the current market price for heat which also is unfavorable (I 12). As mentioned before, increasing DH demand in the city's existing building structure is quite time consuming and costly. As an alternative way to distribute the abundant heat, plans exist to extend the DH network towards the city of Leiden, 30 km North of Rotterdam. Warmtebedrijf agreed with a private energy company that should distribute and sell the heat in Leiden to build transmission pipes until 2020. As construction delayed due to permitting issues, Warmtebedrijf needs to pay compensation fees to this company at present. The fees in addition to the unfavorable pricing situation in Rotterdam create a financial issue for the municipal company. Its future is politically discussed at the moment (I 12). In order to prevent such a situation in other places, the interviewee suggested expert consultations before making such impactful commitments (I 12). In addition, he mentioned optionality in long-term contracts might mitigate financial risks (I 12). Investing in a city asset, like a transmission pipe, in order to enable WHR refers to the governance mode of *Market Facilitation.*

Besides the aforementioned cases in which either the state (Gothenburg) or the city itself (Rotterdam) financed DH infrastructure, current activities in Rotterdam show a way to contract these investments out to private companies. Through **tendering** the city coordinates which company will build and operate new DH systems in the city districts that aim to phase out natural gas (I 11). **Long-term contracts**, usually for around 30 years are supposed to ensure the return of investment for the investor. While contracts with private companies limit options to adopt the system during the contract period, public investments are connected to financial risks for the city (I 11). To address the risk of losing oversight over the activities by private actors, Rotterdam requires transparency on costs and prices charged from customers through the agreements (I 11). Additionally, they plan to monitor compliance to these contracts. Fully withdrawing in case of non-compliance, however, was estimated as difficult according to the respondent (I 11). Long-term contracts can be interpreted as a market incentive, thus also refer to *Market Facilitation.* The municipality has some steering power when assigning the project, however, not more than in a customer relationship, as a market actor.

As a way to realize bigger projects, Turku collaborated with neighboring municipalities in the past. WHR from the waste water treatment plant was installed together with 14 municipalities in 2009 (I 7). The interviewee explained the success of the projects with shared ideas and visions between the municipalities and operating companies. Building partnerships with other municipalities refers to the governance mode of *Network Coordination and Advocacy.*

In addition to high upfront investment costs, operational costs, and therefore **electricity taxation** was highlighted as an economic barrier to WHR by respondents from Gothenburg and Turku. To recover heat from Naatali oil refinery close to Turku, for instance, upgrading would be needed. Present electricity taxation schemes dis favor the investments (I 6). Electricity used for heat pumps in WHR currently does not receive the same tax relief as industrial processes in Finland (I 6).

Similarly in Gothenburg, WHR of low temperature heat sources is hindered through electricity costs for upgrading it (I 1). Using an increased amount of electricity in the local heating system, in general, can be interpreted in different ways, as respondents from Turku illustrate. On the one side, respondents perceived relying on electricity not as an issue as Finland still has a lot of nuclear energy (I 7) and they can buy it from the market (I 6). On the other side, a respondent pointed out that selling electricity is quite beneficial in Finland at present due to current market prices. For this reason, spending electricity within the own system, for WHR, would be less beneficial from an economic perspective (I 7).

Due to the large size of WHR investments, decisions were connected with extensive consultations and **feasibility studies** in all three cities. TSE in Turku currently conducts a feasibility study on WHR from the refinery in Naatali (I 6) and Göteborg Energi on heat storage (I 1). Studies comparing the cost-efficiency of DH with other heating systems were conducted in Rotterdam on district scale (I 11). While in Turku and Gothenburg the municipal energy companies conduct feasibility studies, in Rotterdam the municipality hired an external consultancy firm (I 11).

When the decision to invest in WHR and or DH infrastructure is made, cities can support the process by ensuring a **smooth licensing process.** However, this is seldom an issue according to a respondent from Turku (I 6). In the case of Rotterdam, where pipes should be built across several municipalities, on the contrary permitting eventually was an issue (I 12).

Entities that decide on energy related investments differed between the case cities. In Gothenburg and Turku the municipal energy companies decide on how to develop the systems, mandated or in close exchange with the city council. In Rotterdam on the contrary, several energy companies operate in the city area and most of these are private. Table 21 provides an overview on governance instruments applied to address financial barriers to WHR.

*Table 21 Case cities' approach to address financial barriers*

| Mode | Governance Instruments |
|---|---|
| *Awareness Raising and Outreach* | • Promoting DH at local levels (Gothenburg)<br>• Lobbying for WHR adequate legislation at national level<br>• In alliance with other cities, through city networks (all) |
| *Hierarchical Planning and Regulation* | • Aligning own strategies with national taxation strategy (all)<br>• Promote technology-open planning of buildings and energy infrastructures (Turku) |

A barrier to WHR frequently mentioned in literature, is the risk of the waste heat providing companies shutting down (Chapter 3.1). This issue was not highlighted much by the interviewees. However, Gothenburg's systems exemplifies how this risk can be mitigated. Including the waste incinerator, the city has three large supplier of waste heat. The share of WHR (including waste to energy) makes up around 70% of the local DH mix while no single supplier provides more than 30 % (I 1). The **distribution of heat sources** builds resilience towards potential interruptions (I 1). In fact, their capacities equal mid-size production plants why despite extra costs and emissions, replacing one of them would not be a big issue according to the interviewee (I 1). I addition, Göteborg Energi has **agreements** with the local refineries linking financial compensation to an eventual shut down. However, these contracts might not prevent a shutdown entirely (I 1). The international ownership of the refineries was highlighted in this context, it seemed to lower the perceived influence on decisions. Mitigating economic risks as discussed in a situation where a municipality purchases heat in order to supply it, reflects the governance mode of *Market Provision and Promotion.*

*Table 22 Case cities' approach to address financial risks*

| Mode | Governance Instruments |
|---|---|
| *Market Provision and Promotion* | • Agreement with WHR provider to financially compensate when shutting down (Gothenburg)<br>• Spare capacity and distribution of heat sources (Gothenburg) |
| *Market Facilitation* | • Tendering: Commission private energy companies through long-term contracts (Rotterdam)<br>• Invest in WHR related infrastructure (e.g. transmission pipe)<br>• Through public company (Rotterdam) |
| *Network Coordination and Advocacy* | • Collaboration with neighboring municipalities (Turku) |

### 6.2.5 Approaching Legal Barriers

Several barriers to WHR in the case cities were mentioned that concern national level legislation. In Finland, the tap water regulation requires DH supply temperatures to be at minimum 65°C in order to prevent legionella (I 4). This limits the possibility to decrease temperatures in LTDH further. In the Netherlands, gas infrastructure investments are regulated towards balancing costs for rural regions (I 12). No such regulation exist for DH infrastructure yet. WHR that requires upgrading through heat pumps was hindered by current electricity taxation in Sweden and Finland. Local governments reach limits of direct influence in these cases. They rely on political decisions on national or supranational levels. In all cases, the city governments interacted in some way with upper governance levels. Several interviewees mentioned alliances between cities in order to communicate interests (I 1; I 4; I 11). Rotterdam for instance lobbies for adequate DH regulations through several city networks (I 11). In this case, decoupling the price sealing for DH from natural gas production-costs is discussed (I 11). Also Göteborg Energi aims to advocate DH. Convincing local politicians is important, as those are well connected with friends and colleagues at national governance, according to the informant (I 2).

In addition, the communication with upper governance levels was perceived as crucial for another reason. If local action and investments do not align with the general strategy at national level, it can become a "disaster for the consumer (I 6)". Especially future taxation is decisive for big investments, according a representative of Göteborg Energi. If taxation schemes suddenly change, this can create issues (I 2). Raising awareness for local policy issues and willingness to support DH or WHR exemplifies the governance mode of *Awareness raising and outreach*.

In order to create an overview on the findings presented in this chapter, one can summarize as followed. Institutional barriers to WHR are addressed with *Hierarchical Planning and Regulation*, by the case cities. Mainly through goal setting is applied. Knowledge and cognitive barriers are addressed by *Network Facilitation*, and *Network Coordination and Advocacy*. In order to address demand as a barrier, governance instruments reflecting a broad variety of governance modes are applied, including *Market Facilitation*, *Market Provision and Promotion*, *Network Facilitation*, *Network Coordination and Advocacy,* and *Hierarchical Planning and Regulation*. In order to address financial barriers, the case cities apply *Market Facilitation*, *Network Coordination and Advocacy,* and in order to address legal barriers, *Network Awareness Raising and Outreach.*

# 7 Discussion

Chapter 6 presented the case study's results. This chapter discusses the relevance of the results in relation to prior research in general. It then discusses significant findings and their contribution to practical recommendations for WHR-supportive governance more specifically.

According to the literature review conducted in Chapter 3.2 this is the first work compiling governance instruments local governments can use in order to support WHR. It thus addresses a research gap that can be of interest to close especially for practitioners, but also for researchers by opening up a new perspective on further research. Existing literature on how local governments can support the development of DH did not systematically consider WHR as a heat source (UNEP, 2015). As discussed above, WHR can be realized in DH, however there are important differences between DH and WHR. The roles local governments can take to support DH, described by UNEP (2015), namely *planner and regulator, facilitator, provider and promoter, coordinator and advocate* and the activity of *awareness raising and outreach*, are only operationalized through few governance instruments (UNEP, 2015). The results of this study (including *RQ 1*) are more comprehensive in this regard. Especially, concerning financing issues in large heating infrastructure projects, this study revealed governance modes and instruments UNEP (2015) does not cover. While the study by Lenhart et al. (2015) was limited to the planning phase of WHR projects, this research covers their implementation in addition.

The results are limited to experiences from three case cities. More WHR-supportive governance instruments might occur in other places. Of the governance modes and instruments identified, not all are replicable in every other context, as the context dependency of WHR got confirmed by the results. Replicable, however, is the framework which has been developed and tested in this study. It can be used as a tool for conducting a place dependent analysis of potential governance modes and their implications.

In accordance with the aim of this thesis, generating replicable learnings and recommendations for other localities, the analytic generalizability of the results is discussed in the following. A main difference between the cases, is the ownership structure in local DH systems. Hence, as a first step, the influence of ownership on WHR-supportive governance is discussed.

## 7.1 The Influence of Ownership

The results indicate a main difference between WHR-supportive governance modes and instruments applied in Gothenburg and Turku, with municipal owned DH systems, on the one side, and Rotterdam with multiple private DH companies on the other. This difference confirms, the impact of different ownership structures on governance in DH networks (Rao et al., 2017).

Differences in the governance modes and instruments applied depending on the ownership structure can be explained in multiple ways. One perspective is that the degree of direct control municipalities have on the local DH company, differs. Governance instruments reflecting *Hierarchical Planning and Regulation* that rely on authority, thus might only be applicable to a limited extent to private energy companies. As another perspective, the results highlighted organizational links between municipal energy companies and city administration. They were of different intensity, but in general can explain the accessibility of WHR-relevant, technical knowledge for municipal decision making. Municipal ownership, in addition, can motivate and allow for technical research on WHR within the organizational boundaries of the municipality, in line with *Network Facilitation,* as results can be used internally. Such research or actual WHR projects can be financed in municipal ownership structures through income from operating the DH system. The potential absence of financial and knowledge resources of that kind can explain, why governance modes and instruments in the context of multiple private energy companies differed. The case of Rotterdam showed that local governments in private ownership contexts can create market incentives (*Market Facilitation),* in order to stimulate WHR activities or coordinate action by third actors (*Network Coordination and Advocacy*).

External resources local governments can use in order to address barriers to WHR, were indicated as equal for both ownership structures. In all three cases, the cities collaborate with academia and exchange experiences in city networks in order to address knowledge and cognitive barriers (*Network Coordination and Advocacy)*, and lobby at national level for WHR adequate legislation (*Network Awareness Raising and Outreach)*. In addition, municipalities can support WHR through urban planning and related governance instruments, like land use agreements or building codes, across all ownership structures. This confirms suggestions to support DH through urban planning by UNEP (2015).

## 7.2 Drivers and Barriers to Waste Heat Recovery

Results of the research contribute to an understanding of reasons why local governments are willing to support WHR. The main motivation for WHR, across cases, is to reach municipal climate goals. As climate change mitigation has social benefits as well (Field, 2014), this covers two of the main benefits of WHR.

In addition, some WHR investments in the case of Gothenburg were business-led, indicating the recognition of economic benefits of WHR. Gothenburg's aim to decrease dependency from oil imports in the 1970ies, was referred to as economic reason as well. A decreased dependency from fuel imports, however, can also be linked to social benefits, as contributing to the resilience and thus reliability of DH (Rao et al., 2017). In sum, the results suggest, local governments recognize the environmental and economic benefits of WHR, while they are less driven by social benefits to support the solution.

The results revealed multiple barriers to WHR in the case cities. Some of these barriers confirm prior research on barriers to WHR (Chapter 3.1). Barriers identified that were not mentioned explicitly before, are highlighted in Table 23. These include lack of knowledge on storage technology, insufficient DH connections, and context specific legal barriers. In addition to contributing theoretical knowledge, highlighting legal barriers to WHR, might nurture the political discourse. The results highlight infrastructural barriers to WHR that were included as preconditions, but not as barriers to WHR in the literature review. Issues with the distance between waste heat source and existing DH network, and temperature differences between conventional DH networks and waste heat sources indicate the importance of the design of DH infrastructures for the feasibility of WHR projects.

*Table 23 Current barriers to waste heat recovery in the case cities*

| **Barrier** | **Type of barrier** | **Case City** | **Addressed** |
|---|---|---|---|
| Distance between waste heat source and existing DH network | Infrastructural barrier | Turku, Gothenburg | x |
| Temperature difference between conventional DH and low-temp. heat sources | Technical/ infrastructural barrier | Gothenburg | x |
| Insufficient DH connection while excess heat supply | Market/ infrastructural barrier | Rotterdam | *Market Facilitation, Network Coordination and Advocacy* to increase DH connections |
| Competition with (geothermal) heat pumps | Market barrier | Turku, Gothenburg | *Network Coordination and Advocacy:* Market DH product and services |
| High investment costs | Economic barrier | Turku | Feasibility study; addressing barrier of electricity taxation |
| Electricity taxation | Legal barrier | Gothenburg, Turku | *Awareness Raising and Outreach:* Lobbing at national level |
| Tab water regulation | Legal barrier | Turku | *Awareness Raising and Outreach:* Lobbing at national level |
| DH connections cannot be mandatory | Legal barrier | All case cities | x |
| Lack of knowledge on storage technology | Knowledge barrier | Gothenburg, Turku | *Market Facilitation:* Research projects |

## 7.3 Overcoming Barriers

Multiple governance instruments to explicitly or implicitly address barriers to WHR were identified in the case studies (*RQ2*), as well as in the pre-study (*RQ1*). The results do not include governance approaches to all barriers to WHR mentioned in literature. However, all types of barriers are covered. The relevance of the results for overcoming barriers to WHR in other contexts is discussed in the following. The structure of the section mirrors the structure of Chapter 6.

### 7.3.1 Overcoming Institutional Barriers

The results highlight municipal goals as a central instrument to support WHR. In the cases Gothenburg and Turku, energy goals influenced research activities and investments decisions of the municipal energy companies. This demonstrates the steering capacity of (potential) WHR goals, reflecting *Hierarchical Planning and Regulation*. The research showed that enforcement of energy goals and strategies in the municipalities, was not done in a command-and-control, but rather a suggestive, advisory manner in combination with monitoring. The extent to which private actors can be steered by municipal goals remains uncertain, which indicates this approach might be less suitable for private ownership structures. The importance of connecting municipal goals to WHR is however, a general observation important to consider in other municipalities.

Rotterdam works with market incentives to implement its municipal energy vision. This indicates a way to steer WHR activities through *Market Facilitation* in a context with less municipal actors. By providing transmission pipes for future WHR, the city facilitates a market for waste heat. Present difficulties with the business model and contract, suggest choosing business model- and contractual arrangements carefully. *Awareness Raising and Outreach* to align strategies with upper governance levels, was highlighted as a way to address discrepancies between governance levels and thus mitigating investment risks in all case cities.

Even though principles for joint urban and energy planning exist in theory (Leduc & Van Kann, 2013; Tillie, 2018), these were not used officially in the case cities. The results still demonstrate combining energy and urban planning is important to support WHR. Firstly, this was highlighted by experiences in the city development area Skanssi in Turku. Secondly, current issues of implementing DH connections ex-post in Rotterdam demonstrate infrastructural barriers to WHR that could be solved by urban planning. One interviewee confirmed that check-lists could help to establish the consideration of WHR systematically. This is also a finding to consider for other municipalities.

The issue of changing political and financial climates in public institutions (Lenhart et al., 2015) was not perceived as disturbing in the case cities. This might be specific to the cases. Explicitly, WHR-favoring planning principles could prevent changing strategies and inconsistent investments in localities, where political and personnel changes are more common. Against the background that heating systems are Large Technical Infrastructures which change slowly over time (Palm, 2006), adequate principles might prevent path dependence, in addition.

### 7.3.2 Overcoming Knowledge- and Cognitive Barriers

The results revealed mainly two governance modes that are applied to obtain WHR-relevant knowledge in order to address knowledge and cognitive barriers.

The first approach identified, are research, and more specifically pilot projects by the case cities Gothenburg and Turku, reflecting *Network Facilitation*. The replicability of this approach, however, is limited to access to the respective human- and financial resources. The second approach identified is exchanging existing information in national or supranational city networks, reflecting *Network Coordination and Advocacy*. This approach seems widely replicable, as applied by all three case cities and not requiring much human or financial resources. The importance of city networks to exchange knowledge on WHR confirms the importance of city collaborations in climate governance (Jänicke, 2017).

The results do not reveal if other modes of governance could also be applied effectively to address knowledge barriers to WHR, as indicated by the analytical framework (Chapter 3.4, Table 6). In theory, local governments could stimulate research by financial incentives (*Market Facilitation*), or mandating research (*Hierarchical Planning and Regulation*). Funds allocated for projects on WHR by the EU (Celsius, 2020a; ReUseHeat, 2017c) give an example of such approach by upper governance levels.

The case cities do not use a systematic approach to identify potential waste heat sources. Whether the 'on-the-go' approach, reported from both, Gothenburg and Turku, is effective or not, remains uncertain. Experience from Rozenburg, Rotterdam indicate that waste heat sources might be quite straight forward to recognize at district scale. For larger areas, systematic approaches seem advantageous, especially in contexts in which responsibilities are quite distributed or personnel often changes. The pre-study (*RQ1*, Chapter 5) revealed that Frankfurt uses a waste heat registry, and London uses waste heat maps in order to assess and monitor local WHR potentials. Several mapping tools for waste heat exist that are open-source and can be used for free by local authorities to visualize waste heat potentials (Hotmaps Project, 2020; PLANHEAT, 2019; THERMOS, 2019). Results by Krasatsenka et al. (2017) suggest that simple maps can already provide inspiration to projects. If financial or knowledge resources for extensive waste heat mappings are limited, municipalities can collaborate with universities, like the example of Vienna (Loibl et al., 2017) and Rotterdam (Broersma & Fremouw, 2011) demonstrated.

While the case studies confirmed that the availability of waste heat sources is quite context dependent, a variety of waste heat sources that are currently utilized in pilot projects were identified in the pre-study (Chapter 5, Table 16). This shows, WHR is possible in many different contexts. It also shows that pilot projects are a common way to address knowledge and cognitive barriers to WHR at present.

### 7.3.3 Overcoming Financial Barriers

Long payback periods of WHR projects as a barrier to WHR (ReUseHeat, 2019a) were confirmed by the results of this study. Two approaches to overcome this barrier were identified, both reflect *Market Facilitation*. Firstly, a low-interest loan by the city of Paris allowed the local DH company to expand the network (UNEP, 2017). Secondly, zero-interest loans in the case of Rotterdam facilitated the conversion of natural gas heated houses to DH. Both examples demonstrate how WHR investments were possible with prolonged planning horizons.

The results further indicate that public companies plan rather long-term than private companies. The city of Rotterdam founded a public company in order to invest in transmission pipes while no private company was interested. Negative experiences with business model- and contractual situation, in this case, suggest carefulness when designing agreements. Same counts for long-term contracts when out-sourcing investments and permitting private investors to operate a system for a specific amount of time. The advantage of avoiding financial risks can create the disadvantage of limited flexibility to adjust DH systems to technological or market changes.

In the case of Gothenburg, investments in WHR could be realized in the 1970ies through financial support by the national government. Despite the positive effects of national level support in this case, the results confirm, that funds and grants should not replace a WHR business case. This was specifically highlighted by one of the interviewees.

When a DH network is implemented, it is flexible towards different types of heat sources from a technological perspective. This flexibility of DH facilitated a smooth introduction of WHR in Gothenburg which confirms a main benefit of DH (Rao et al., 2017). It also demonstrates that financial barriers to WHR might be lower in contexts which have DH in place already, like in Northern Europe or the former Soviet Union (Werner, 2017). Considering potential long-term benefits of DH systems, might favor DH over to other heating systems in investment decisions.

Another way to address financial barriers to WHR is expressed by the business model applied in Gothenburg. Sharing economic benefits of WHR between the DH company and the waste heat provider, might motivate joint investments. No example of joint investment could be identified within this study. This might confirm a lack of knowledge on how to distribute risks and benefits (Lygnerud et al., 2019; Moser et al., 2016). As described before, knowledge barriers to WHR are addressed for instance by research projects or exchanging information between cities. A research projects addressing WHR business models and contractual options specifically, is the EU-funded ReUseHeat project (ReUseHeat, 2017c). Local governments could carry this approach forward by bringing relevant stakeholder together and providing information in accordance with *Network Coordination and Advocacy.*

A distribution of financial risks is reached through the distribution of investments on several waste heat sources, as shown in the case of Gothenburg. Such decentralization of heat sources is in accordance with the 4th generation DH and is favored by the technical opportunities of LTDH (Lund et al., 2014).

### 7.3.4 Overcoming Market Barriers

The collaboration with large scale customers as a strategy to establish DH on the market was relevant across all cases. While most respondents referred to procurement by public housing companies, reflecting the governance mode of *Market Provision and Promotion*, it also can apply to arranging partnerships with third actors in accordance with *Network Coordination and Advocacy,* especially in places in which public heat demands are limited.

A competitive advantage of WHR that can be used to overcome market barriers to WHR is its sustainability performance. In the development district Brunnshög in Lund, where WHR from a large-scale research facility in LTDH is currently being implemented, recovered heat was successfully marketed to property developers. The sustainability aspect was a good selling point, however, the local energy company needed to market it to property developers individually. This information was obtained from an additional interview with Lund's municipal energy company (I 13). The need to proactively market DH and DH services was also highlighted by a respondent from Turku's energy company, as not many customers would know DH can be more sustainable than other heat sources.

The results suggest that city development projects are a special opportunity for implementing WHR solutions. Several governance instruments identified in this study can be applied to foster WHR in developing structures, for instance building codes (Gothenburg), land use agreements (Turku), or requirements to assess WHR potentials (pre-study, Tokyo) which are examples of *Hierarchical Planning and Regulation*. Alternatively, local governments can facilitate partnerships to implement WHR solutions (Turku) which reflects *Network Coordination and Advocacy*. *Network Facilitation* through actively participating in the development of WHR in city development projects, like in Skanssi (Turku), can also address market barriers to WHR.

### 7.3.5 Overcoming Legal Barriers

*Awareness Raising and Outreach* in form of lobbying at national level for local interest, in order to overcome current institutional barriers to WHR was highlighted across all cases. As each of the case cities is among the biggest cities in its respective country, their political influence on national level might be high. The replicability of this approach to smaller cities remains unclear as they might have limited human and financial resources. This highlights the importance of alliances and city networks through which smaller cities can organize themselves.

To summarize, the governance modes and instruments identified in the case cities differed mainly with regards to ownership of local DH companies. Gothenburg and Turku, with municipal energy companies, supported WHR mainly through *Hierarchical Planning and Regulation*, *Market Provision and Promotion*, and *Network Facilitation*. Rotterdam, with mainly private energy companies, supports WHR through *Market Facilitation*, and *Network Coordination and Advocacy*. All case cities lobby for WHR adequate policy frameworks at upper governance levels which refers to *Network Awareness Raising and Outreach*. An overview of the governance instruments that were discussed in this chapter as 'replicable' is provided in the Tables 24-26.

*Table 24 Replicable governance modes and instruments applied in* **Gothenburg**

| Barrier to WHR | Governance Instruments | Governance Mode |
|---|---|---|
| WHR against business model of selling heat;<br>high investment costs | Energy goals<br>Energy strategy | *Hierarchical Planning and Regulation* |
| WHR competes against other heat sources | Local building codes (not dis favoring DH) | *Hierarchical Planning and Regulation* |
| Lack of demand or supply | Act as provider of waste heat and large consumer | *Market Provision and Promotion* |
| Lack of knowledge on storage technology; business model and policy options | Research and pilot projects, e.g. on storage technology | *Network Facilitation* |
| Lack of knowledge and awareness on technology, business model and policy options | Initiating and coordinating European research project | *Network Awareness Raising and Outreach* |

*Table 25 Replicable governance modes and instruments applied in* **Turku**

| Barrier to WHR | Governance Instruments | Governance Mode |
|---|---|---|
| WHR is against current business model of selling heat | Energy goals<br>Energy strategy | *Hierarchical Planning and Regulation* |
| WHR competes against other heat sources | Building requirements and land use agreements in city development project | *Hierarchical Planning and Regulation* |
| Lack of demand or supply | Large DH consumer | *Market Provision and Promotion* |
| Lack of knowledge on local WHR options, storage technology, two-way DH system technology and business model | Identifying potential waste heat sources<br><br>Pilot projects: two-way LTDH, heat storage | *Network Facilitation* |
| Lack of WHR-supportive legislation | Lobbing at national level | *Network Awareness Raising and Outreach* |

*Table 26 Replicable governance modes and instruments applied in* **Rotterdam**

| Barrier to WHR | Governance Instruments | Governance Mode |
|---|---|---|
| Lack of market incentive | Investing in transmission pipe<br>Long-term contracts for companies expanding DH | *Market Facilitation* |
| Lack of demand | Low interest loans for converting houses | *Market Facilitation* |
| | Facilitating partnership with social housing company | *Network Coordination and Advocacy* |
| Lack of adequate DH regulation | Lobbying on upper governance levels | *Network Awareness Raising and Outreach* |

## 7.4 Reflection of Methodological Choices

The methods applied in this study provided useful information in order to answer the research questions. The literature review confirmed benefits and potentials of replacing primary heat sources with WHR. The overview on current barriers to WHR and actors in WHR systems underlined the relevance local governments can have in supporting WHR solutions in their contexts. Furthermore, reviewing literature on urban energy and transition governance confirmed the lack of studies on WHR specific governance. At the same time, it inspired the idea to use different governance modes as an analytical framework. Combining both, different roles local governments can take to support DH and hierarchical, market and network governance allowed to differentiate the governance modes that are used in WHR governance in more detail than it would have been possible with either of these typologies. The suitability of the resulting framework to WHR-supportive governance was confirmed by both, results of the pre-study and the case studies.

The selection of case studies provided a variety of learnings on WHR-supportive governance instruments, drivers and barriers to WHR in the case cities. As Rotterdam was the only case with a private ownership setting, an imbalance towards results from a context with municipal ownership was created. This imbalance got reinforced through a lack of responsiveness of potential interview partners. Having yet another case with private ownership could have given more information on possible benefits with this.

Due to language barriers, data collection for the case studies mainly relied on interviews. The level of English spoken by both the interviewees and the researcher influenced this process. Data collection was further influenced by the Coronavirus/Covid-19 pandemic. Due to travel restrictions, all interviews were conducted via Skype or telephone and not in person as intended. The results from the interviews helped answering the research questions and there are no obvious detected losses by doing the interviews over phone or online. One potential loss could be that interviews tend to be shorter and shallow. However, this was not perceived as an issue by the author.

The analytical framework was useful in structuring data collection and analysis. The coding software helped to process data derived from 14 interviews in total. The two-step approach of analyzing each of the cases individually, before conducing a cross-case analysis helped to analyze similarities and differences between the case cities in their respective context.

The strong influence of the individual context on WHR-supportive governance is highlighted by the results of this study. This confirms the suitability of a case study method for approaching this topic. Including a preparatory research step, the multiple-case study method was useful in answering the research questions. However, it allows not for direct generalizations. As discussed before in this chapter, on an analytical level, the results provide replicable learnings.

# 8 Conclusions and Recommendations

This thesis highlighted that amongst the multiple non-technical barriers that currently hinder the implementation of WHR solutions in DH systems, many can be addressed by local governments. Taking a multiple-case study approach, the research identified a variety of governance instruments that cities and regional governments can use in order to support WHR projects. The identified instruments differ in the role local governments take and the logic through which barriers to WHR are addressed. Based on a literature review on prior research on energy and transition governance, an analytical framework was developed, consisting of six different modes of governance:

- *Hierarchical Planning and Regulation,*
- *Market Facilitation,*
- *Market Provision and Promotion,*
- *Network Facilitation,*
- *Network Coordination and Advocacy*, and
- *Network Awareness Raising and Outreach.*

This framework guided the analysis, while answering two research questions:

***RQ1**: Which WHR-supportive governance instruments can be identified in earlier research?*

Examples of WHR-supportive governance instruments mentioned in academic and grey literature, as well as on websites, were identified. They include energy goals and strategies, energy potential mapping, a waste heat registry, DH connection policy, self-governance in public procurement, investments in city assets, and facilitating partnerships. The most common instrument were pilot projects. The compilation served as a pre-study for the analysis of WHR-supportive governance in Gothenburg, Turku and Rotterdam that was conducted in order to answer the second research question:

***RQ2:** How have three case cities supported WHR in the past and how are they supporting WHR at present?*

The analysis of the case cities revealed that climate goals are the main motivations to support WHR at present, but also economic factors were a driver for the implementation of WHR in the past. The main barrier to WHR in the cities at present are high upfront investment costs, unfavorable electricity taxation, competition with other heating technologies, and insufficient DH connections.

The governance modes and instruments applied by the case cities differed between municipal and private ownership of local DH systems. In the two cases with municipal ownership, Gothenburg and Turku, there was an emphasis on addressing institutional barriers to WHR by *Hierarchical Planning and Regulation*, and market barriers through *Market Provision and Promotion.* In the case with mainly private ownership, Rotterdam, market barriers to WHR were addressed through *Market Facilitation*, and *Network Coordination and Advocacy.* Knowledge barriers to WHR were addressed by *Network Facilitation*, through research and pilot projects, in Gothenburg and Turku, while all three cities exchanged knowledge between cities to address knowledge barriers, referring to *Network Coordination and Advocacy.* Strategies to address legal barriers to WHR were similar between the cases too, involving lobbying for adequate legal frameworks at upper governance levels which refers to *Network Awareness Raising and Outreach.*

The emphasis of WHR-supportive governance in the case cities was influenced by the 'maturity' of individual aspects that are all relevant for WHR in DH, including DH pipes, connections and demand, waste heat sources, financial resources, and national level support.

By taking into account further contextual factors that led to the success of WHR and WHR-supportive governance in the case cities, the replicability of the results was discussed. By complementing the results from the case studies (*RQ 2*) with results from the pre-study (*RQ 1)* the following recommendations for local governments willing to support WHR can be formulated.

## 8.1 Governance Recommendations

Local governments should clearly define a WHR-supportive direction, including explicit goals, responsibilities, and processes (Table 27). They should explicitly integrate WHR in municipal energy goals and strategies. Coordinating action across sectors and align approaches with upper governance levels thereby is crucial. Where local governments only have limited control over local DH companies, municipal statements to support WHR can be complemented with governance approaches suggested in Table 30, for instance, market incentives or arranging partnerships to stimulate interest for WHR. In any ownership structure, WHR-supportive, combined urban and energy planning should be applied. Clear planning and decision-making principles should get defined, and if possible be binding. On a more ad-hoc, but also systematic basis, local governments should take the initiative and facilitate partnerships that lead to the realization of WHR projects.

*Table 27 Governance recommendations to address institutional barriers to waste heat recovery*

| **Define a clear direction** | | |
|---|---|---|
| **Instruments** | **Mode of Governance** | **Context** |
| Define municipal **energy goals and strategies**<br>- Coordinate action across sectors<br>- Align approach with upper governance levels | *Hierarchical Planning and Regulation* | Any ownership structure<br>- If control over private actors is limited (non-municipal ownership structures) combination with other approaches is recommended |
| Combine urban and energy planning<br>Define **clear decision making principles**, e.g. 'energy hierarchy' | *Hierarchical Planning and Regulation* | Any ownership structure |
| Initiate or facilitate partnerships to realize WHR | *Network Coordination and Advocacy* | Any ownership structure |

Local governments should establish systematic processes to assess and monitor local WHR potentials. Open-source tools and collaboration with academia can support this process. The geographical scope of the focus area determines the assessment's dimension and thus the need for aid. Assessing WHR possibility on different spatial scales, can help to identify potential projects for individual districts or neighborhoods. A documentation is recommended in any case to prevent the loss of knowledge if personnel changes. Knowledge on which waste heat sources are possible to utilize, can be obtained by exchanging experiences with other localities, for instance in city networks. If sufficient financial and knowledge resources are accessible in municipal energy companies or through research funds, local governments can contribute to the generation of new knowledge by implementing pilot projects. If needed, these can be conducted in collaboration with academia or potential technology providers. In this way, current knowledge and cognitive barriers to WHR are addressed (Table 28).

*Table 28 Governance recommendations to address knowledge barriers to waste heat recovery*

| **Obtain knowledge through collaboration** | | |
|---|---|---|
| **Instruments** | **Mode of Governance** | **Context** |
| Assess and document local WHR potentials systematically on different geographical levels (e.g. district, neighborhood scale) | *Network Facilitation* | Any context |
| Collaborate with universities on mapping of local waste heat potentials | *Network Coordination and Advocacy* | Low human and financial resources |
| Pilot and other research projects, e.g. in collaboration with academia or technology provider | *Network Facilitation* | High human and financial resources |
| Exchange existing knowledge between cities, e.g. through city networks | *Network Coordination and Advocacy* | Low human and financial resources |

Local governments should consider the long-term benefits of DH infrastructure investments and institutionalize long-term planning. If economically feasible, public resources should be used to invest in WHR or related infrastructure, like transmission pipes. To mitigate financial risks of such investments, business models and potential contracts should be designed carefully. Risks can be distributed additionally through decentralized systems with several waste heat sources. DH systems at low temperatures (LTDH) can increase the number of potentially accessible industrial and urban heat sources and thus support decentralization. To distribute the financial burden of projects, joint investments together with waste heat providers (industry) can be considered, as both parties benefit from the valorization of the waste heat. Joint investments with other municipalities benefitting from projects can be an additional option.

Where local governments have limited resources to invest in WHR themselves, they can create conditions that allow private investors to plan long-term. Instruments that can be used are low- or zero-interest loans or long-term contracts that permit actors to operate a DH system for the given pay-back period.. Again, careful contracting is important in order to avoid technological path-dependence and ensure cost-efficiency of the system throughout the contract period. Local governments should consider that long-term contracts with private operators generally limit their influence on the system during the contract period. The suggested instruments (Table 29) allow to address financial barriers to WHR.

*Table 29 Governance recommendations to address financial barriers to waste heat recovery*

| **Favor WHR through long-term planning** | | |
|---|---|---|
| **Instruments** | **Mode of Governance** | **Context** |
| Consider long-term benefits of investments in DH infrastructure | *All* | Any |
| Invest in public WHR infrastructures<br>- Select business model and contract design carefully<br>- Distribute risks by decentralizing heat generation; using potentials of low-temperature DH (LTDH)<br>- Consider joint investments with waste heat provider | *Market Facilitation* | Sufficient financial resources |
| Facilitate long-term planning of private actors (e.g. through low-or zero-interest loans or long-term contracts and permits)<br>- Design contracts carefully | *Market Facilitation* | Insufficient financial resources |

In order to address market and legal barriers to WHR, local governments can lobby for WHR-supportive policy frameworks on upper governance levels. As changing legislation can be a long- or mid-term process, local governments can proactively start implementing WHR where it is economically feasible, for instance in city development projects. In order to support or create markets for recovered heat, municipalities can procure recovered heat in public buildings, or arrange collaborations that convince other actors, like housing companies, to do so. If financial resources are accessible, local governments can stimulate WHR by providing key infrastructures, like transmission pipes.

Where it is economically feasible and beneficial from an environmental perspective, local governments should not miss the chance to integrate WHR in new infrastructures. Opportunities to support WHR through architectural measures or urban planning, for instance in city development projects, should be used. Requirements to assess WHR potentials in every city development project can institutionalize this procedure. Further instruments, like land use agreements, or building codes can be used to foster WHR-supportive building design and DH connections. Depending on human and financial resources, local government can either implement WHR projects themselves or act as a mediator that facilitates partnerships between actors that otherwise would not collaborate. Table 30 summarizes the suggested instruments to address market related barriers to WHR.

*Table 30 Governance recommendations to address market barriers to waste heat recovery*

| **Support competitiveness at present and in the future** | | |
|---|---|---|
| **Instruments** | **Mode of Governance** | **Context** |
| Raise awareness for policy needs at national governance levels | *Awareness Raising and Outreach* | Any |
| Procure recovered heat in public buildings | *Market Provision and Promotion* | High public heating demands |
| Stimulate heat trading through providing key infrastructures, e.g. transmission pipes | *Market Facilitation* | Sufficient financial resources |
| Arrange partnerships with third actors that supply or procure recovered heat | *Network Coordination and Advocacy* | Low public heating demands |
| Support WHR integrative infrastructures and building designs (e.g. through requirements to assess WHR potentials, and use agreements, or building codes) | *Hierarchical Planning and Regulation* | City development project |
| Participate proactively in the development and testing of WHR solutions | *Network Facilitation* | City development project; Sufficient human and financial resources |
| Facilitate partnerships between third actors and provide them with WHR-relevant information to stimulate projects | *Network Coordination and Advocacy* | City development project; Insufficient human and financial resources |

A general recommendation for developing WHR in DH systems, is to be equally aware of all conditional aspects. Only if *waste heat source(s)* and *heat demand* exist, *DH infrastructures*, including pipes and connections, are in place and *financial resources* are available, WHR projects are possible. *Political support* on national level, in addition, can determine the economic sustainability of solutions through supportive, or at least not disfavoring legislation. As all these aspects are interdependent, local governments should address them simultaneously when developing WHR systems. If one aspect is disregarded, like lack of sufficient demand for installed DH capacity, or lack of political support, problems are likely to occur. Central coordination is recommended in order to keep an overview on status and future development potentials of local WHR systems.

In sum, this research identified several replicable governance instruments that local governments can use to support the recovery of waste heat in their context. Based on the key learnings, recommendations for further research are presented in the following.

## 8.2 Recommendations for further Research

The results of this research mainly rely on experiences made in three case cities. However, several other cities proactively support WHR at present, as examples from answering *RQ 1* indicate. Further case studies that analyze WHR-supportive governance modes and instruments in these cities, including successful as well as unsuccessful experiences, are needed in order to expand the knowledge on different governance options. Research on further examples of WHR-supportive governance could improve the governance recommendations this work provides, for instance by diversifying recommendations in accordance with the context specificity of WHR. Especially, research into how local governments can stimulate WHR activities in private companies would be needed. Many DH systems in Europe and elsewhere are privately owned and the results of this study were limited in this regard. Further research is needed on governance options to address barriers to WHR that this study did not suggestions for.

Furthermore, research on successful WHR business models is needed in order to allow the smooth implementation of technical solutions. Local governments might benefit from this knowledge in the role of a customer, supplier or trader of waste heat. Uncertainty about the right kind of business model challenged WHR in one of the case cities and very little research on this topic exists to date.

The results of this study highlighted the dependency of local WHR ambitions on national level support. Research on policy options upper governance levels have to support WHR is therefore needed. Ex-ante evaluations on WHR-supportive policy, for instance on adopted electricity taxation could support political decision making.

Further research and development of technical solutions, like heat storage, is needed in order to overcome current technical barriers to WHR in conventional and LTDH systems. In order to quantify environmental and social benefits of individual WHR solutions and to compare them with alternative heat sources, context specific Life Cycle Assessments are needed. Such assessments, again, can inform decision making.

The study revealed that lacking financial and human resources make it difficult for local governments to conduct feasibility studies on local WHR opportunities. Academia can initiate or support existing governance ambitions by generating such feasibility studies for cities or regions.

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# Appendix

## 1. Data Collection. Interviews

*Appendix 1 presents details of data collection, specifically details of the interviews conducted*

| City | Code | Role and Organization | Interview Date | Channel |
|---|---|---|---|---|
| **Gothenburg** | **I 1** | Strategic Business Developer, Göteborg Energi | February 28th 2020 | Telephone |
| | **I 2** | Development Engineer, Göteborg Energi | February 28th 2020 | Skype |
| | **I 3** | Environmental Investigator, City of Gothenburg | March 3rd 2020 | Telephone |
| **Turku** | **I 4** | Project Manager Heat, Turku Energia | March 18th 2020 | Skype |
| | **I 5** | Product Manager Heat, Turku Energia | March 9th 2020 | Telephone |
| | **I 6** | CEO, Turun Seudun Energiantuotanto Oy (TSE) | March 12th 2020 | Telephone |
| | **I 7** | Senior Advisor Energy, City of Turku | March 25th 2020 | Skype |
| | **I 8** | Project Manager Urban Planning, City of Turku | March 27th 2020 | Telephone |
| **Rotterdam** | **I 9** | Researcher, investigating REAP Rotterdam | March 13th 2020 | Skype |
| | **I 10** | Researcher, co-developing REAP Rotterdam | March 13th 2020 | Skype |
| | **I 11** | Program Manager, Urban Development, City of Rotterdam | March 19th 2020 | Telephone |
| | **I 12** | Politician, Social-Democrats, City Council Rotterdam | March 24th 2020 | Telephone |
| **Lund** | **I 13** | Project Leader, Kraftringen | March 27th 2020 | Telephone |
| | **I 14** | Project Manager Brunnshög, Lund Municipality | March 7th 2020 | Written |

## 2. Data Analysis. Coding Structure

*Appendix 2 presents details of data analysis, specifically codes used in the Thematic Analysis*

- **Motivation/driver**
- **Activities by the local government**
    - Interaction with other public actors
    - Interaction with private actors
        - Hierarchical Planning and Regulation
        - Market Facilitation
        - Market Provision and Promotion
        - Network Facilitation
        - Network Coordination and Advocacy
        - Network Awareness Raising and Outreach
- **Governance instruments**
        - Hierarchical Planning and Regulation
        - Market Facilitation
        - Network Facilitation
        - Market Provision and Promotion
        - Network Coordination and Advocacy
        - Network Awareness Raising and Outreach
- **Barriers to WHR**
    - Technical barriers
    - Knowledge barriers
    - Cognitive barriers
    - Financial or Business related barriers
    - Market related barriers
    - Legal barriers
    - Institutional barriers
- **Enabler for WHR**
- **Local context, WHR related**

# 3. Case Cities. Background Information

*Appendix 3 presents WHR-related background information to the three case cities Gothenburg, Turku and Rotterdam*

| Gothenburg | | References |
|---|---|---|
| **Population** | 570.000 | City of Gothenburg (2019) |
| **DH system** | - Production capacity of 1.800 MW or 3.500-5.000 GWh/year<br>- DH introduced in 1953, today 90% of all heating<br>- DC since mid-1990s<br>- Owned and operated by municipal energy company Göteborg Energi (monopoly) | Göteborg Energi (2020), Göteborg Energi (2009)<br>I 1 |
| **DH sources** | - CHP<br>- Waste to energy<br>- WHR from two oil refineries (30 %)<br>- Several small biofuel, natural gas and oil boiler<br>- WHR from sewage water | Göteborg Energi (2020),<br>Göteborg Energi (2018) |
| **WHR projects** | - WHR from St1, former Shell, refinery, since 1980<br>- WHR from Preem refinery, since 1998<br>- WHR from sewage water, since 1983/1985<br>o 4 heat pumps, total heating capacity of 160MW<br>o Temporary operation when electricity prices are competitive compared to alternative production in 2019 this were 3 000h (125 days), little over 300 GWh/year<br>o At waste water treatment plant: water arrives at 12°C and gets cooled to 3°C | Göteborg Energi (2009)<br>I 1, I 2 |
| **Driver** | - In 1970ies: oil crises<br>- Then: Air quality<br>- Since 1990ies: national carbon tax<br>- Today: climate neutrality goals of the city (City of Gothenburg, 2014)<br>o by 2030, DH 100% RE, waste incineration and industrial WHR | Göteborg Energi (2009)<br>I 1, I 2 |
| **Additional activities** | - Gothenburg has been initiator and coordinator of the CELSIUS project, funded by the EU | (Celsius, 2020a) |

| **Turku** | | **References** |
|---|---|---|
| **Population** | 190.000 | City of Turku (2019a) |
| **DH system** | - Introduced in 1976<br>- 2.000 GWh DH annually<br>- 90 % of the buildings<br>- Owned and operated by municipal energy company Turku Energia (monopoly)<br>- Electricity production in the region: energy company Turun Seudun Energiantuotanto Oy (TSE) | Turku Energia (2020)<br>Lyytikäinen (2020)<br>I 4 |
| **DH sources** | - CHP Naatali, since 1960<br>  o Two older coal fueled boiler (soon to shut down)<br>  o Biofuel boiler (built in 2018)<br>- Two smaller plants, a 40 MW, one biomass and one pellets<br>- Heat pumps at the wastewater treatment plant in Kakola, since 2009<br>- Fuel mix 2019: 50% from biomass, 10% heat pumps, 1,8 % recovered heat, appr. 35% fossil fuels | Turku Energia (2020)<br>TSE (n.d.) |
| **WHR projects** | - WHR from sewage water, since 2009<br>  o Owned by the TSE, but operated by Turku Energia<br>  o 160 GWh/ year DH (15.000 households)<br>  o 30 GWh / year (90 %) DC<br>- Pilot project two-way LTDH (65 °C) in city development district Skanssi<br>  o Residential use, appr. 8 000 inhabitants until 2030<br>- Currently assessed: WHR from Neste refinery in Naatali<br>  o Potential of 150 MW | City of Turku (2019)<br>City of Turku (n.d.) |
| **Driver** | - **Carbon neutral** city by 2029 ($800^{th}$ birthday of the city)<br>- Heating sector with 39% emission largest CO2 emitter<br>  o Goal to increase share for RE in DH to 70 % by the end of 2020; phase out coal by 2022 | Turku City Council (2018) |

| **Rotterdam** | | **References** |
|---|---|---|
| **Population** | 640.000 | CSB (2019) |
| **DH system** | - Thermal capacity of 105 MW; 417 GWh/annually<br>o Heat demand of around 50,000 households<br>- Supply temperature between 120 and 90°C<br>- Network in the North of the city owned and operated by *Eneco* (private); in the South of the city by *Nuon* (private)<br>- In 2010 city founded party city owned company *Warmtebedrijf Rotterdam* to develop a 26 km heat transmission connection between Rotterdam's waste incinerator in Rozenburg (harbor area) and the networks owned by *Eneco* and *Nuon* (investment of €38 million) (UNEP, 2015, p. 74)<br>- Transmission pipe from harbor to city owned and operated by *Warmtebedrijf*, since 2013 | Warmtebedrijf Rotterdam (2020) |
| **DH sources** | - *Warmtebedrijf*: waste to energy<br>- *Eneco* and *Nucon* additionally use other energy sources<br>- e.g. *Uniper* operates coal and natural gas CHP in Rotterdam and provides DH to *Eneco* | Kreijkes (2017), Uniper (2020) |
| **WHR projects** | - High energy potential in harbor area of Rotterdam - many large energy consumers and producers:<br>o 9 gas fired power plants<br>o 3 coal and biomass co-combustion,<br>o 1 biomass<br>o one waste incinerator<br>o 5 oil refineries<br>o 42 chemical sites<br>- Could supply city twice as big as Rotterdam with sufficient waste heat (Warmtebedrijf Rotterdam, 2018)<br>- Rotterdam collaborates in an alliance amongst others with private energy *Eneco* to expand network to The Hague and Westland horticulture region. This will be built with financial support by the national government (Eneco, 2019)<br>- WHR from Shell refinery, since 2018<br>o DH to 16 000 households<br>o *Shell* installed WHR technology, *Havenbedrijf Rotterdam* is responsible for delivering heat to *Warmtebedrijf Rotterdam* that delivers it to local distributors | Kreijkes (2017), Warmtebedrijf Rotterdam (2018),<br><br>Eneco (2019) |
| **Driver** | - Rotterdam emits between 16 and 25% of Dutch GHG emissions, mostly from the port<br>- Goal to halve GHG emissions by 2025 compared to 1990 levels<br>- Goal to phase out natural gas until 2050<br>o Ambition by the national government, by 2021 municipalities need to indicate how they will research this goal with vision and implementation plans<br>- Resilience Strategy: development of a clean energy road map considering waste heat above other sources<br>- Tradition in progressive climate adaptation and mitigation politics; geographical location on the Rhine-Meuse-Schelde river delta, which makes vulnerability to sea level rise visible<br>o Took part in the Celsius project as a demonstrator city | Gemeente Rotterdam (2018)<br><br>I 10<br><br>Celsius Initiative (n.d.a) |

# 4. WHR supportive governance instruments

*Appendix 4 presents results of the preparatory research step, answering RQ1: examples for WHR supportive governance instruments identified in theory and practice*

| Governance Instruments | Description<br>Example | City | Source |
|---|---|---|---|
| *Hierarchical Planning and Regulation* | | | |
| **Objectives, targets, strategies** | Until 2050 – **100% RE and recovered energy** (20% generated locally)<br>*Strategy includes*:<br>- Intensify energy recovery and exploitation<br>- Advocating for WHR (laundries, data centers, bakeries) | Paris, France | City of Paris (2018) |
| | Until 2030 – **100 % RE and recovered energy in DH**<br>Until 2030 – **primary energy use** for electricity and heat ≤ 31 MWh/inhabitant | Gothenburg, Sweden | City of Gothenburg (2014) |
| | Until 2050 – all buildings **carbon neutral**<br>Until 2030 – all districts **natural-gas free**<br>*Strategy includes*:<br>- District-by-district approach<br>- Fuel switch to **higher use of waste heat**<br>- Looking to **capture waste heat from data centers**<br>- **expand DH network** to cover 50-60 % or the houses | Amsterdam, Netherlands | City of Amsterdam, (2020) |
| | Until 2050 – **Carbon neutral city**<br>*Strategy includes*:<br>- Utilize local and RE, like solar and **waste heat**<br>- **Heat mapping** and energy **masterplans** at district level, including low-temperature waste heat sources. | London, UK | Greater London Authority (2018) |
| | Until 2050 – **lower GHG emissions 95 %** (compared to 1990)<br>*Strategy includes*:<br>- **Waste Heat Registry** | Frankfurt, Germany | City of Frankfurt (2019) |
| **DH planning policy** | **Mandatory assessment of DE opportunities** in land-use planning | Tokyo, Japan | (UNEP, 2015) |
| **DH connection policy** | **Obligatory DE connection** for non-domestic buildings (hotels, shopping centers, government offices, the planned multi-purpose stadium) in the Kai Tak area | Hong Kong, China | (UNEP, 2015) |

| | | | |
|---|---|---|---|
| | DH connection (not purchase) as requirement for new buildings | Rotterdam, Netherlands | (UNEP, 2015) |
| **Obligatory WHR** | Obligation to recover waste heat when generated | Theory | (UNEP, 2015; Wheatcroft et al., 2019). |

| **Governance Instruments** | **Description Example** | | **City** | **Source** |
|---|---|---|---|---|
| *Market Facilitation* | | | | |
| **Financing/ fiscal incentives** | Low interest loans for DH expansion | | Paris, France | (UNEP, 2017) |
| | Tax-free zone for pilot projects | | Amsterdam, Netherlands | (UNEP, 2015) |
| | **Tax breaks and investment subsidies** for WHR infrastructures | | Theory | (Wheatcroft et al., 2019) |
| | Tax breaks for waste heat feed-ins | | Theory | (Pehnt et al., 2011) |
| **City assets** | Transmission line for WHR | | Ashan, China | (UNEP, 2015) |
| | Heat storage | | Rotterdam, Netherlands | (SCIS, 2020). |
| *Market Provision and Promotion* | | | | |
| **Consumer for DH** | In public facilities, like schools or hospitals | | Theory | (UNEP 2015) |
| **Self-governance** | public procurement of recovered energy | | Theory | (UNEP 2015) |
| *Network Facilitation* | | | | |
| **Pilot projects** | Sewage water | | Tokyo, Japan | (UNEP, 2015) |
| | | | Seattle, USA | (UNEP, 2015) |
| | | | Vancouver, Canada | (UNEP, 2015) |
| | | | Oslo, Norway | (UNEP, 2015) |
| | | | Cologne, Germany | (Celsius, 2020e) |
| | | | Gothenburg, Sweden | (Boye Petersen, 2017) |
| | Data Centre | | Mäntsälä, Finland | (Sitra, 2019) |
| | | | Brunswick, Germany | (ReUseHeat, 2017a) |
| | | | Bergen, Norway | (GreenByte, 2020) |
| | **Metro** | | Islington (London), UK | (Celsius, 2020f) |
| | | | Berlin, Germany | (ReUseHeat, 2019b) |
| | **Industry** | **Liquid gas** | Castelnuovo del Garda, Italy | (Celsius, 2020d) |
| | | **Steel** | Ravne, Slovenia | (Waste Heat, 2019b) |
| | | **Automotive** | Charleville-Mézières, France | (Dalkia, 2018) |
| | | **Food** | Vienna, Austria | (Waste Heat, 2019a) |
| | LTDH several waste heat sources | | Brunnshög Lund, Sweden | (COOL DH, 2019) |
| | | | Høje-Taastrup, Denma | (COOL DH, 2019) |

| | | | |
|---|---|---|---|
| *Network Coordination and Advocacy* | | | |
| **Heat mapping** | Open source map | Amsterdam, Netherlands | (Amsterdam Smart City, 2019) |
| | Open source map , interactive, including existing and proposed heat networks, potential heat supply sites | London, UK | (CSE, 2020) |
| | Scientific Study | Vienna, Austria | (Loibl et al., 2017) |
| | Scientific Study | Rotterdam, Netherlands | (Broersma & Fremouw, 2011) |
| **Waste Heat Register** | Cadaster for waste heat from waste water, industry, commerce and large data-centers | Frankfurt a. M., Germany | City of Frankfurt, 2019) |
| **Facilitation Cooperation** | Initiate and coordinate **cross-sectoral planning, dialogue and learning** | Rotterdam, Netherlands | (Lenhart et al., 2015) |
| | Coordinate energy exchange between industries | Granollers, Spain | (THERMOS, 2020) |
| *Network Awareness Raising and Outreach* | | | |
| **Research projects** | Initiate or participate in WHR related research projects | Gothenburg, Sweden | (Celsius, 2020a) |
| **On upper governance levels** | Communicate and lobby for WHR with upper (national or supranational) governance levels | Theory | (UNEP 2015) |

# 5. Interview Guide

*Appendix 5 presents details of data collection, specifically the interview guide used in semi-structured interviews*

**Introduction:**

1. Interviewee's role and time in the organization
2. Connection to WHR project

**Part 1:**

3. Which projects of the aforementioned type exist in your city at present? Which state are they in?
4. What is the main motivation of your organization to participate in these projects?
5. With which *public actors*, your organization collaborates regarding waste heat recovery? How?
6. With which *non-public actors*, the public actors collaborate regarding waste heat recovery? How?
7. Did the *local authorities* support the project?
    a. Trough *regulative governance instruments* (like standards, obligations)? If yes, please specify.
    b. Trough *financial governance instruments* (like subsidies, taxes)? If yes, please specify.
    c. Trough *public investments*? If yes, please specify.
    d. Through *soft governance instruments* (like communication strategies, visions)? If yes, please specify.
    e. Through *bringing relevant actors together*? If yes, please specify.
    f. Through *providing data and/or information*? If yes, please specify.
    g. Other?

**Part 2**

8. What were *challenges or difficulties* when realizing the utilization of waste heat in your city?

9. Which challenges or difficulties regarding waste heat recovery still exist today?

    a. *[Energy utilities only*:] Does waste heat recovery compete with your other business models or heat sources?

    b. Lack of best practices on how to distribute risks and benefits (business model)?

    c. Lack of legal framework?

    d. Risk of unstable supply (short-and long-term)

    e. [*Local decision makers only:]* Lack of knowledge on technological opportunities and policy options

    f. [*Local decision makers only:]* Lack of authorization or responsibility

    g. [*Local decision makers only:]* Lack of capacity and know-how for the implementation of projects

    h. [*Local decision makers only:]* Short political planning horizon and changing political and financial climates

10. Where there any other factors besides measures from the public authorities that lead to the success of the projects in your city? Which?

11. Are there further potentials to utilize waste heat in your city? Which actions by the local government would facilitate their utilization?