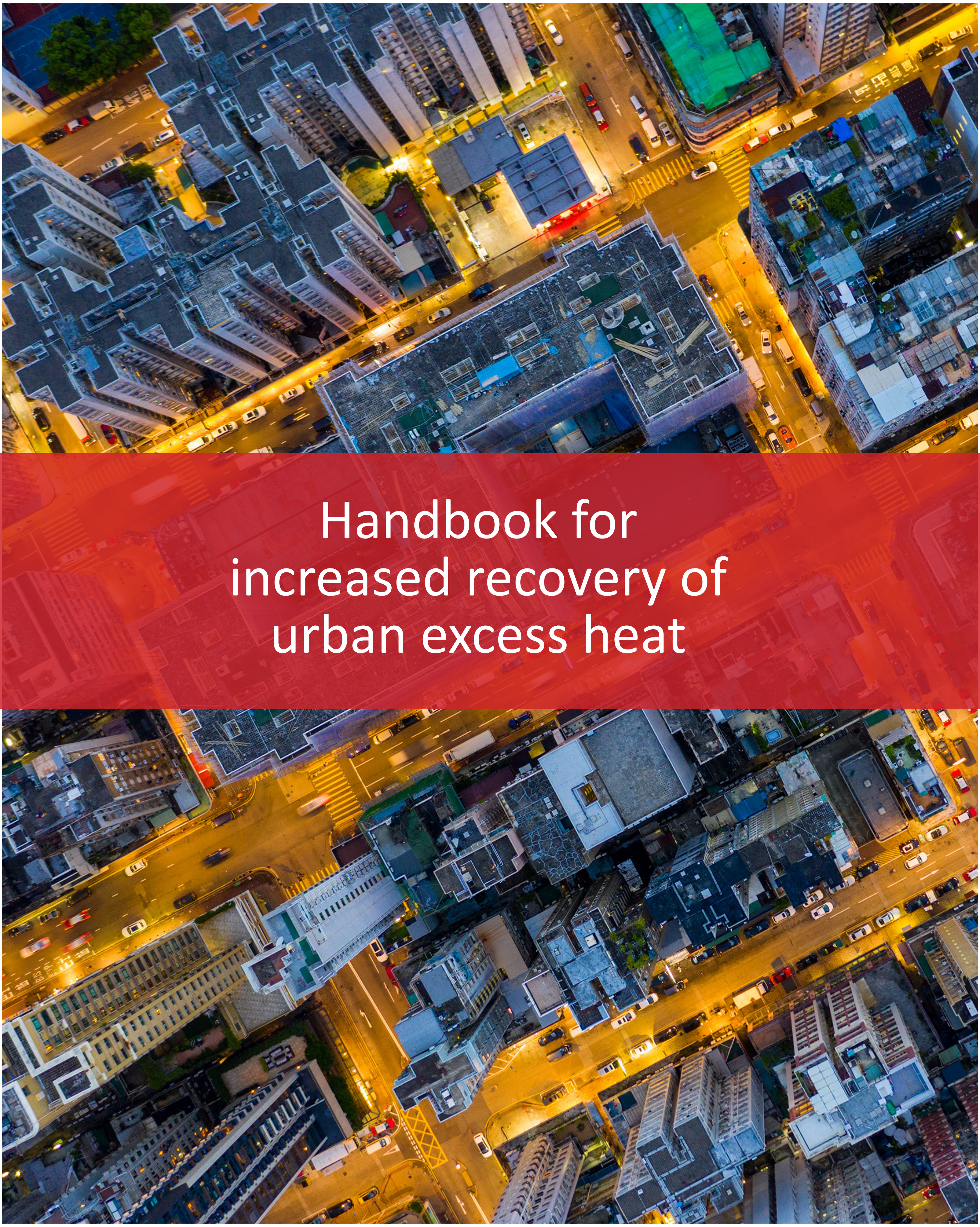


Handbook for increased recovery of urban excess heat

ReUseHeat

ABBREVIATIONS USED IN THE BOOK

DH	District Heating
DHC	District Heating and Cooling
DHN	District Heating Network
LTDH	Low Temperature District Heating Network
LTDHC	Low Temperature District Heating and Cooling Network
CHP	Combined Heat and Power
MVP	Minimum Viable Product
WS	Workshop
BMC	Business Model Canvas
TRL	Technical Readiness Level
O&M	Operation and Maintenance
HP	Heat Pump

The ReUseHeat project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 767429.

The ReUseHeat project will showcase replicable models enabling the recovery and reuse of excess heat available at urban level, with the aim to increase energy efficiency of district heating and cooling systems in cities across Europe.

The following partners make up the ReUseHeat team: The Swedish Environment Research Institute, Euroheat and Power, London School of Economics and Political Science, the CARTIF foundation, Tractebel Engineering, Halmstad University, Aalborg University, RINA-Consulting, Centre Scientifique et Technique du Batiment, Electricité de France, Metropol Nice Cote D'Azur, Metroul, Veolia Energie Deutschland, Naturgy Energy Group, Dansk Fjernvarme Forening, Ochsner Process Energy Systems and ASIME.

The handbook was drafted with the support of selected partners and edited by Kristina Lygnerud at the Swedish Environment Research Institute.

PREFACE

This book aims to consolidate information from low temperature waste heat recovery sites. Apart from technical validation, the ReUseHeat project has generated knowledge about the urban waste heat potential in Europe, main stakeholders, how to write efficient contracts and low temperature business model characteristics. The book targets five stakeholder groups. These are urban waste heat owners, district heating companies, policy makers, investors and customers. The heterogeneity of stakeholders is challenging when writing a handbook as stakeholder interest and previous knowledge about district heating varies. In the first chapter of the book, the concept urban waste heat is introduced. Thereafter, information on business aspects is provided (stakeholders, value chain, risks, contracts and business model characteristics). Section three showcases the demonstrator concepts (waste heat recovery from datacenter, hospital, metro and awareness creation about urban waste heat recovery) and performance data. Throughout the writing of the handbook, it was identified that it is important to compare the cost of the customer when choosing amongst different heating alternatives. Therefore, a simple model was derived to compare costs of heating alternatives. It is presented in chapter four. In Chapter five thoughts on the future development of district energy (addressing policy, business and leading up to ReUseHeat recommendations) are provided.

This book was written within the ReUseHeat project. The work on the book was initiated after the first out of five years of activity to ensure that the consortium would be engaged in its development and to capture the knowledge generated on an ongoing basis. The book was put online on the project website six months prior to project closure with the intent to allow interested stakeholders to read and comment on it. Furthermore, input collected from trainings on ReUseHeat demonstrators as well as input from a co-creation session at the closing conference of the book are incorporated into the handbook, found in the last chapter (chapter six). The final version of the book will be ready and placed on the ReUseHeat webpage in September 2022. The webpage remains in operation until 2024. The book will not only exist in digital format but also in 600 printed copies, distributed to relevant stakeholders after September 2022. All partners of the consortium have contributed to the writing of the book. A special thanks is given to Henry Wynn and Ed Wheatcroft at London School of Economics for the support on contracts, risks and business models. A special thanks also to Daniela Leonte at Tractebel Engineering for support on the completion of the handbook. Kristina Lygnerud at IVL, the Swedish Environment Research Institute has coordinated the ReUseHeat project and has edited the handbook.

EXECUTIVE SUMMARY

Urban waste heat

Waste heat, surplus heat and excess heat are synonyms for heat generated by a process but not absorbed by that process. The temperature of the heat depends on the process generating it. In ReUseHeat, we refer to urban waste heat, which is generated in different parts of urban infrastructure. In a future where fossil fuels are phased out, volumes of waste for incinerations are lowered (due to circular economics) and the competition about biomass (residuals from forestry) is high, waste heat sources are important. At the demonstration sites of the project, the heat to recover comes from an IT infrastructure (datacenter), a service sector building (hospital) and a transport infrastructure (metro tunnel). One demonstrator creates awareness about urban waste heat recovery. It showcases how waste heat can be recovered from water (sea and sewage). Urban heat sources are called “low-temperature heat sources” and can be used directly in low-temperature district heating systems or high-temperature systems by using a booster heat pump to bring the heat source to the necessary temperature. ReUseHeat demonstrators have targeted the latter use. Urban waste heat potential and sources are presented and discussed in the first chapter of this book.

Demonstration sites

The demonstration sites have been at the heart of the ReUseHeat project (outlined in chapter three). Four were foreseen but three were realized. The demonstration site that failed was to recover waste heat from metro tunnels. The demonstrator faced a number of challenges. The main three were (i) that the original partner had to exit the project. The second challenge was that the location of the installation was to be rebuilt by the metro operator with would have postponed the ReUseHeat installation by 2 years. The third challenge was that the new location necessitated a transmission line pipe of approximately 100 meters from heat source to customer driving cost. In combination with increasing material costs post the Pandemic the necessary stakeholders withdrew from the installation as it was not seen as a cost competitive alternative. In spite of terminated implementation, several learnings were made on metro-system heat recovery and the two concepts derived for installation are outlined in the book as well as learnings from the attempts to install the demonstrator in Bucharest and Berlin. To recover urban waste heat into existing district heating networks necessitates a system innovation encompassing the low temperature heat source, a heat pump and a district heating network. In isolation, none of the items is new technology but the combination has limited implementation and validation. One important hurdle to waste heat recovery in general but to urban waste heat recovery in particular is that the awareness of the potential to use the waste heat is low. To enhance awareness, the three foreseen demonstration sites that recover waste heat hands on have been complemented by a demonstrator showcasing the heat sources resorted to for heating and cooling. For this kind of visualization tool to work it is important both to have accurate data from the system and to find the appropriate level of communication to the end user further explained in the book.

Datacenter heat recovery

The demonstrator exploits waste heat from a data center to provide heat for 400 newly built homes and a shopping center in the outskirts of the city. BS|ENERGY is a local energy company that provides heat and electricity to the city. The newly built houses are connected to a low temperature DH system built, owned and operated by BS|ENERGY. Around 40% of the city's heating demand is met through a high temperature district heating network powered by a high efficiency cogeneration plant (CHP). The electricity generated from the CHP supplies electricity to the electrical grid. Additional heating demand is met by gas boilers, powered with natural gas, which is also supplied by BS|ENERGY. The demosite is of interest to BS|ENERGY since it allows for the provision of DH to the newly built area without expansion of the current DH capacity. Instead, a low temperature DH network was built in the format of an ‘island’ that is linked to the existing DH distribution network. This is a long-term risk management strategy since the urban waste heat recovery investment only meets the baseload demand and any additional demand can be supplied through the high temperature network. Data centers produce large quantities of heat and require significant cooling to avoid equipment damage. Cooling therefore contributes a great deal to the overall running costs. By supplying a district heating network with excess heat, a win-win solution is established: the data center reduces its cooling costs, and the DH company obtains heat that can be used to increase the heat capacity without additional investments in large scale production capacity. There is great potential for this kind of arrangement, particularly given the rise in demand for cloud-based services and online storage which directly increases demand for data centers. The data center provides warm water at 25 °C which is piped to the “energy station” where the temperature is increased to 70 °C via a heat pump. The return water holds a temperature of 18°C which reduces the need for cooling of the data center. The hot water produced by the heat pump is piped to the residential and commercial areas to provide heating. The water returns to the energy station at a temperature of 40°C. A Buffer tank is used to store hot water so that it can be distributed when required (at the cost of some degree of heat loss). This demonstrator won an international award (Global District Energy Climate Award) in the newcomer category in 2019.

Hospital heat recovery

The demonstrator recovers heat from a hospital building for use in a local district heating network to provide heating and cooling for the hospital. A hospital was chosen because it is a common urban tertiary building with local district heating and cooling infrastructure and therefore the potential for replication is high. Southern European hospitals (the demonstration site is located in Madrid) have high cooling needs throughout the year whilst there is also a high thermal energy demand. During the Winter, cooling is still needed for surgery rooms and other areas with special air requirements. Furthermore, heating demands are high, not only for space heating in the Winter, but also for domestic hot water production as well as for process heat (e.g. sterilization and cleaning) over the whole year. The hospital chosen is the Hospital Universitario Severo Ochoa, in Madrid. The hospital is situated in the municipality of Leganés and is a public university hospital that offers a variety of medical services to citizens in Madrid. Heat is recovered from a cooling system (from the cooling towers) and replaces the usage of gas. The project has been developed and executed by ASIME who are currently responsible for maintenance of the hospital’s cooling and heating systems.

Metro heat recovery

The demonstrator was first to recover waste heat from the metro system of Bucharest and then from a metro tunnel in the west of Berlin city center. In Berlin, the heat would have been used for a three-story building owned by the metro operator and connected to a low-temperature, local network. Metro systems produce a great deal of heat from electric motors, breaking equipment and ventilation on the trains that pass through. This can make metro stations uncomfortably hot in the Summer months. Modern metro stations are typically equipped with ventilation systems, but these can be costly to run. In terms of metro systems, waste heat recovery, as well as providing heat for use in a district heating system, can also be beneficial for the owner of the heat source. Recovery of heat naturally provides cooling, thus either reducing running costs or providing cooling that would not otherwise have been provided, therefore increasing the comfort of the customers.

It was foreseen to reuse waste heat from a tunnel in the metro network in Berlin. The waste heat source foreseen was a tunnel in which the temperature is 8-15°C in the Winter and 27°C in the Summer. The heat recovery was to be realized with an air to water heat exchanger as the source and a water-to-water heat pump during the Winter season. The heat recovery system would be made with a multi fan-coil unit which would be placed on a platform within the tunnel.

The local district heating network is a low temperature network (50°C) extending approximately 200 meters. The installation would be established for the local, low temperature grid but, through the buffer tank, a link would be prepared to connect the ReUseHeat heat recovery to the city-wide district heating network of Berlin (approximately 2,000 kilometers long), one of Europe’s oldest and it operates at high temperatures. The metro implementation was worked upon by METROUL (first installation) and OPES (second and third foreseen installations).

Awareness creation

The awareness creating demonstrator is a means to communicate DHCN relevant information to end-user and the wider public, as energy performances achieved from low temperature waste heat recovery. The objective of the demonstrated dashboard is to create awareness amongst building owners and end-users (tenants) of heat that it is possible to recover waste heat from urban sources and to understand the working principles of low temperature district energy solutions in general. The dashboard is a collaboration between a local authority (the Metropolitan authority of Nice, with the ambition to create awareness amongst its residents), an energy company (EDF, interested in providing a new service to district energy network operators) and a research organization (CSTB, supporting the design and simulation of the dashboard). The dashboard is designed to be applicable to any renewable or waste heat low temperature network (regardless of low temperature heat source). In a future stage, it is foreseen to incorporate other information that is useful to end-users (for example weather forecast information). Thereby providing customers with information that is tailored to their demand allowing them to reduce their energy bills by better understanding how the network operation is related to weather conditions.

Characteristics of urban waste heat recovery investments

The most important gain from urban waste heat recovery is that the support decarbonization. Compared to heat generated from incineration processes, waste heat recovery has a green footprint. Furthermore, urban heat sources tend to be stable. For example, waste heat from sewage water or metro systems comes from city infrastructures with long lifetime thereby providing stable heat volumes and temperatures independently of season. Datacenters also generate waste heat across the year but, as a result of urbanization, it is common that they shift location every 10-15 years. When the first contract of land use expires the datacenter does not always get a prolonged contract. Instead, the ground is used for construction of new buildings. In ReUseHeat, the urban heat sources have been inserted into existing networks replacing other heat sources. In this context, the gain is that an expansion of the heat producing units is not needed saving capital expenditure. In systems with a number of low temperature heat sources in combination the resilience to shock of the system increases as it is unlikely that several heat sources stop providing heat into the grid at the same time. The low temperature heat source is owned by an agent external to the process of the district heating company. Engaging with the waste heat owner introduces the element becoming dependent on the waste heat supplier. This is a circumstance that also applies to high temperature waste heat recovery. To settle the situation, contracts are needed. Efficient contracts have proven important also in the ReUseHeat installations. Information on urban waste heat recovery contracting, risk-exposure, ownership and business model characteristics is found in chapter two.

Three major learnings from ReUseHeat

In the last section of the book, three major learings from ReUseHeat are summarized. These are:

Technology is not the main stopper of urban waste heat recovery. Rather, it is the low level of maturity amongst necessary stakeholders to realize the opportunity, to identify who to collaborate with and how.

Urban waste heat recovery investments have features that will be standard in the future energy system. They, for example, make use of locally available heat sources without any incineration but as the price of carbon is not reflecting its future damage costs they are not seen as cost competitive in the short term.

Waste heat is mentioned and encouraged but important pieces of regulation are missing for derisking the investments and for creating a demand of waste heat recovery solutions as early as in the construction phase of buildings. The problem is there for waste heat recovery in general but even more pronounced for urban waste heat since it is a largely unknown possibility.

CONTENTS

1. An Introduction to Urban Waste Heat

In this chapter district heating is introduced, and the concept of urban waste heat is addressed (1.1). The potential of the heat sources studied in the ReUseHeat project is presented and the implications of using such sources are provided (1.2).

1.1 District heating

District heating (DH) recovers resources that are otherwise lost and tends to distribute heat from a central unit through district heating networks (DHN) to buildings. Heat is often recovered from electricity production in combined heat and power generation (CHP) as well as from various other waste heat streams. When waste heat is not available, fuel is typically incinerated to generate heat.

District heating has existed in commercial form since the late 1880s [1]. The technology has developed from the first steam-based systems into systems with a supply temperature of approximately 80–90˚C in the third-generation systems that currently dominate [2]. In these systems, as much heat as possible should be transferred to buildings for technical efficiency. In the future, when fossil fuels are no longer used, the economy is circular (waste fractions to be incinerated are lower), residuals from the forest industry and alternative biomass are used for purposes other than incineration for heat generation, renewable alternatives will be needed. Such heat sources can be geothermal, solar, ambient air and sea heat as well as different fractions of waste heat.

Waste heat, surplus heat and excess heat are synonyms for the heat generated by a process that is not absorbed by that process. In this book we use them interchangeably. The temperature of the heat depends on the process generating it. In ReUseHeat, we refer to urban waste heat, which is generated in different parts of urban infrastructure. At the demonstration sites of the project, the heat to recover comes from an IT infrastructure (data centre), a service sector building (hospital), a transport infrastructure (metro tunnel) and water (sea and sewage). Urban heat sources are called “low-temperature heat sources” and can be used directly in low-temperature district heating systems or high-temperature systems by using a booster heat pump to bring the heat source to the necessary temperature. ReUseHeat demonstrators have targeted the latter use.

Lower district heating temperatures offer cost advantages throughout the distribution chain from heat supply to heat consumption. In a publication from 2021 [3], nine potential cost savings of reduced system temperatures are identified:

1. More geothermal heat can be extracted from wells because lower temperature geothermal fluid can be returned to the ground
2. Heat pumps require less electricity when extracting heat from heat sources with temperatures below the heat distribution temperature because lower pressure can be applied in the heat pump condensers
3. More excess heat can be extracted as the lower temperatures of the excess heat carrier will be emitted to the environment (waste heat will be recovered and not sent into the ambient air)
4. More heat can be obtained from solar collectors as their heat losses are lower, thereby improving conversion efficiencies
5. More electricity can be generated per unit of heat recycled from steam CHP plants as higher power to heat ratios can be obtained with lower steam pressure in the turbine condensers
6. More heat can be recovered from flue gas condensation as the proportion of vaporised water (steam) in the emitted flue gases can be reduced
7. Heat storage capacities will increase as lower return temperatures can be used in conjunction with high-temperature outputs from high-temperature heat sources
8. Heat distribution losses will decrease with lower average temperature differences between the fluids in the heat distribution pipes and the environment
9. Plastic pipes can be used instead of steel pipes to reduce expenses.

1.2 Urban waste heat potential and implications of using urban waste heat sources

ReUseHeat has four demonstration sites focusing on different urban excess heat sources: heat from cooling data centres, heat from cooling towers in a service sector building (hospital), heat from metro tunnels and heat from water (sea and sewage). In the project, the potential of these low-temperature urban heat sources was analysed. In addition to the heat sources explicitly addressed in the project, the analysis encompasses excess heat from food production, food retail, residential sector buildings and other service sector buildings. The information presented below predominantly comes from deliverable 1.4 and 1.9, please resort to these for additional detail.

In the analysis, a distinction was made between the gross available volumes of available excess heat. This is heat that is available at a source and recoverable at the evaporator side of any given compressor heat pump. These estimations simply state what magnitudes of recoverable excess heat is present regardless of how it might be recycled. Accessible excess heat is heat that is accessible at the secondary side of any given compressor heat pump. It is heat that is ejected from the condenser as the sum of the available excess heat and electric energy introduced to the process. To assess the accessible excess heat, only heat sources within 2 kilometres of the DHN were included. Accessible excess heat is very important as it allows the identification and discussion of other factors that might moderate or hamper the realisation of the excess heat utilisation project. ReUseHeat concludes that the expected heat sources should be monitored carefully so they can be quantified at an early stage. The full available excess heat potential is estimated at 1.84 EJ per year for the EU-28, whereas the accessible volume is 1.41 EJ per year.

The maturity of district heating varies across the EU-28. In the EU-28, there are 3,280 district heating areas that contain 4,113 unique district heating systems. Out of these systems, 90% are found in countries with over 100 networks: Austria (473 systems), France (448), Poland (424), Denmark (458), the Czech Republic (394), Sweden (305), Germany (257), Slovakia (221), the UK (199), Finland (179), Estonia (150) and Hungary (107). As the number of networks demonstrates, in some smaller countries there are many, smaller networks (as in Austria and Denmark, for example) comprising much of the heat market. In other countries, a large number of networks compared to the total number of networks in the EU-28 (as in France and Germany, for example) reveals that they represent a low share of the overall heat market.

Figure 1 shows total heat demand for buildings in Europe with the proportion that could be provided through urban waste heat and the distribution of the ReUseHeat sources. The urban heat represents ~ 10% of the heat demand. From the figure it is identifiable that out of the 1.41 EJ of urban waste heat the majority comes from sewage water (44%), buildings (service sector 21% and residential 8%) and datacenters (19%). Only 3% comes from metro systems.

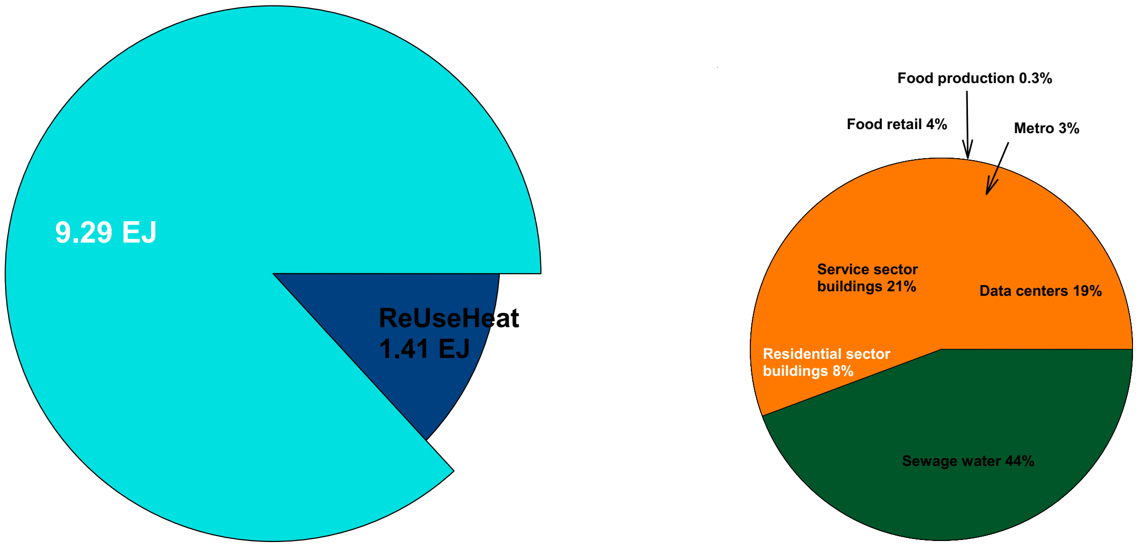


Figure 1. Energy from ReUseHeat as a part of the European heat demand for buildings further split (to the right) into the seven individual sources of ReUseHeat urban waste heat

To define the heat sources' potential, the typical recovery types, their temperature ranges, temporality and the heat pump conversion were identified as important elements. This information is presented in Table 1. The assessments presented here are based on an assumed coefficient of performance of 3.0 for the heat pump.

Table 1. Recovery types, temperature ranges, temporality and the heat pump conversion type for the heat sources.

Excess heat source	Recovery type	Temperature range °C	Temporality (seasonal)	Heat pump conversion type
Data centre	Server room air cooling systems	25–35	Principally constant	Air to water
Metro stations	Platform ventilation exhaust air	5–35	Variable	Air to water
Food production facilities	Rejected heat from refrigeration processes	20–40	Principally constant	Liquid to water
Food retail stores	Rejected heat from refrigeration processes	40–70	Principally constant	-
Service sector buildings	Central cooling devices	30–40	Variable	Liquid to water
Residential sector buildings	Central cooling devices	30–40	Variable	Liquid to water
Wastewater treatment plants	Post-treatment sewage water	8–15	Principally constant	Water to water

1.2.1 Excess heat from data centres

Excess heat from data centres is derived mainly from the cooling processes for information technology (IT) equipment installed in server halls, i.e., the removal of heat to maintain the optimum operating temperatures for installed components. Heat is generated in several server components, especially the processors, memory chips and disk drives. There are 997 data centres in the EU-28 that are located within 2 kilometres of a district heating network, generating 270.6 PJ of accessible excess heat per year. Of the excess heat generated, 73% comes from countries with more than 10 PJ/year in excess heat volumes from data centres: Germany (58.6 PJ/yr), France (45.8PJ/yr), the UK (27.8PJ/yr), Italy (20.5 PJ/yr), Spain (15.3 PJ/yr), Poland (15.3 PJ/yr) and Sweden (13.3 PJ/yr).

Assessing the accessible heat volumes from this heat source is difficult as the data centres are unwilling to share information about their activity. ReUseHeat's main findings on data centre heat recovery are that data centres scale their activity up at the pace of the needed IT loads and a completed data centre building does not necessarily reflect a full IT load and full heat recovery potential. Another key finding about data centres is that they often move after some years of operation because of the city growing into the area of the original data centre location. This can inhibit heat recovery into DHNs as the heat source can end up being located too far away from the network for heat recovery to be economically feasible.

1.2.2 Excess heat from metro stations

Excess heat from metro stations is derived from the station platform and tunnel exhaust ventilation air shafts, i.e., by removing sensible and latent heat from air heated primarily by the electricity used to drive the train carriages, auxiliary systems and heat dissipated during braking as trains stop at platforms. There are 1,852 metro stations within 2 kilometres of a district heating network and 48.6 PJ of excess heat that can be accessed in the EU-28. The largest numbers of metro stations are found in France (441), Spain (407) and Germany (318). A total of 37 cities in the EU-28 have heavy rail (metro) systems in place, listed in Table 2.

ReUseHeat found that the metro station and the location of heat usage must be close to each other to avoid pipelines between the heat source and heat user as this is very costly. Also, a metro-system is heavily regulated to ensure safety and construction and maintenance access to any installations that necessitate the use of tunnels will be limited to times when the trains are not running.

Table 2. EU-28 cities with metro system.

Amsterdam	**Budapest**	**Lisbon**	**Newcastle**	**Stockholm**
Athens	**Catania**	**London**	**Nuremburg**	**Toulouse**
Barcelona	**Copenhagen**	**Lyon**	**Paris**	**Turin**
Berlin	**Genoa**	**Madrid**	**Prague**	**Vienna**
Bilbao	**Glasgow**	**Marseille**	**Rennes**	**Warsaw**
Brescia	**Hamburg**	**Milan**	**Rome**	
Brussels	**Helsinki**	**Munich**	**Rotterdam**	
Bucharest	**Lille**	**Naples**	**Sofia**	

The temperature of this heat source is seasonal as shown in Figure 2. The temperatures are the lowest during winter and peak in summer. ReUseHeat found that heat recovery in metros will be useful for both heating and cooling purposes. The need for cooling will depend on the surrounding soil. For example, the soil around the metro system in London is clay. Over time, the clay is heated up by metro activity, serving as a heat storage keeping the temperature in the London metro system high year-round. This was not the case in the location considered for metro heat recovery in Berlin.

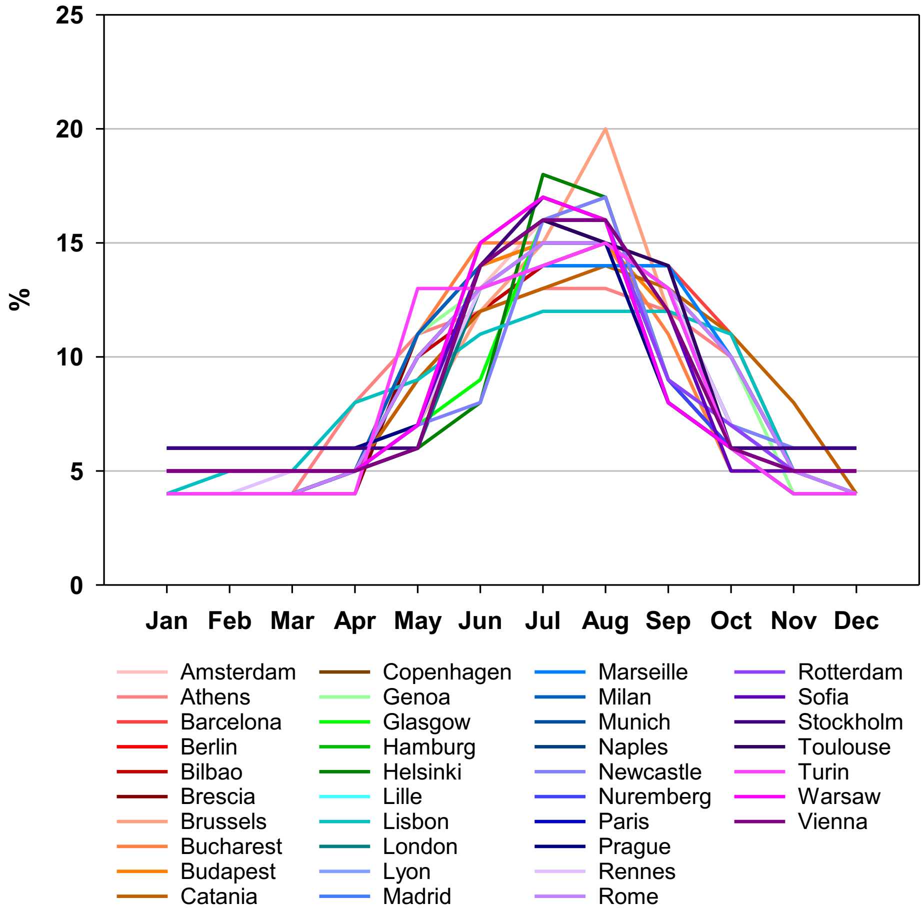


Figure 2. Seasonality of heat source temperatures.

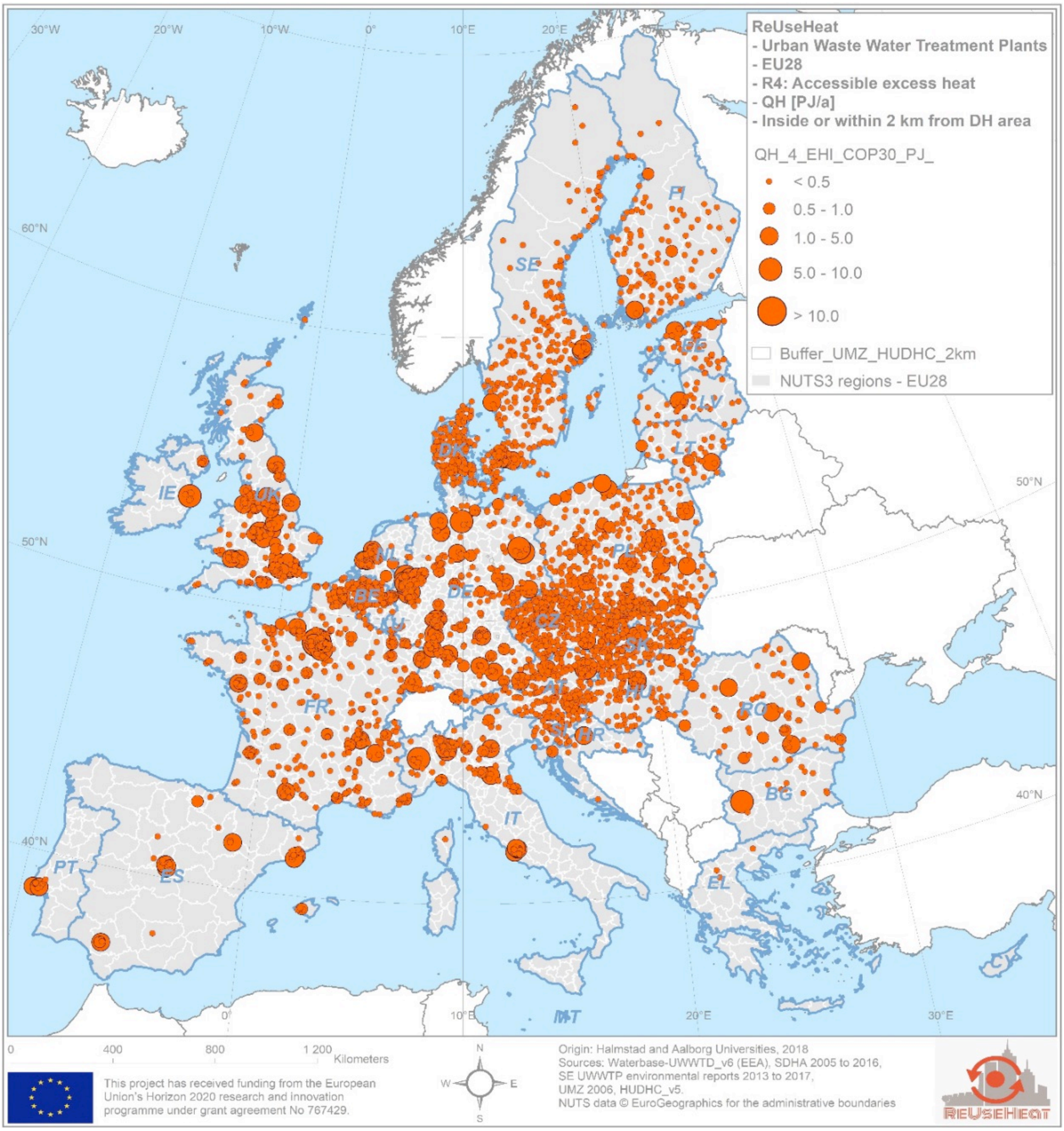
1.2.3 Excess heat from cooling service sector and private buildings

The excess heat that must be removed from a building to maintain a given indoor temperature is equal to its cooling demand. From service sector buildings in urban areas within 2 kilometres of a district heating network, 291.5 PJ/yr can be recovered. Of this available excess heat, 79% comes from Italy (68.9 PJ/yr), Spain (59.4 PJ/yr), France (50.2 PJ/yr), Germany (26.5 PJ/yr) and the UK (24.1 PJ/yr). The corresponding number for residential buildings is 109.7 PJ/yr, of which 74% comes from Italy (44.2 PJ/yr), Spain (26.3 PJ/yr) and France (10.6 PJ/yr).

1.2.4 Excess heat from sewage water

The potential for heat recovery from urban waste-water treatment plants, specifically, sewage, has been established based on the fundamental condition that external heat is rarely added to sewage plant treatment processes. This suggests that it is fair to assume the heat content present in post-treatment sewage water should approximately equal the heat volumes designated for hot water preparation in residential and service sectors. Given some partial blending of “day-water”, or rainwater, a certain degree of cooling of the total volume of incoming sewage occurs. There are 3,982 waste-water treatment plants within 2 kilometres of a district heating network with a potential of 624.9 PJ/yr in the EU. Of this potential, 69% is in countries offering larger volumes than 20 PJ/yr: Germany (121.2 PJ/yr), the UK (93 PJ/yr), France (85.5 PJ/yr), Poland (66.8 PJ/yr), Austria (23.9 PJ/yr) Spain (22.5 PJ/yr), Sweden (20 PJ/yr) and the Czech Republic (20 PJ/yr).

The accessible excess heat from 3,982 EU-28 urban waste-water treatment plants located within 2 kilometres of urban district heating areas is shown in Figure 3.



Origin: Halmstad and Aalborg Universities, 2018
Sources: Waterbase-UWWTD_v6 (EEA), SDHA 2005 to 2016,
SE UWWTP environmental reports 2013 to 2017,
UMZ 2006, HUDHC_v5.
NUTS data © EuroGeographics for the administrative boundaries

Figure 3. The 3,982 waste-water treatment plants within 2 kilometres of a district heating network in the EU-28.

1.2.5 Excess heat from food production and retail

Food production as an industrial activity can be divided into processing and preserving meat, fish, fruit and vegetables or manufacturing oils and fats, dairy products, grain mill products, starches, baked goods, animal feeds, beverages and tobacco. There are 669 food production units within 2 kilometres of a district heating network in the EU-28. From them, 4.8 PJ is accessible per year. The potential for heat recovery from food retail stores is derived from systems for perishable food that needs refrigeration for preservation. The continuously refrigerated storage areas and display cases make food retail stores attractive providers of waste heat. Within 2 kilometres of a district heating network, there are 20,171 stores with an excess heat potential of 59.7 PJ per year. Of this waste heat, 55% comes from countries offering larger volumes than 5 PJ/yr: Germany (14.5 PJ/yr), France (5.7 PJ/yr), Poland (6.7 PJ/yr) and the UK (6 PJ/yr). The high density of food retail stores in the EU-28 is illustrated below (41,832 stores). Figure 4 shows the distribution of EU-28 food retail stores.

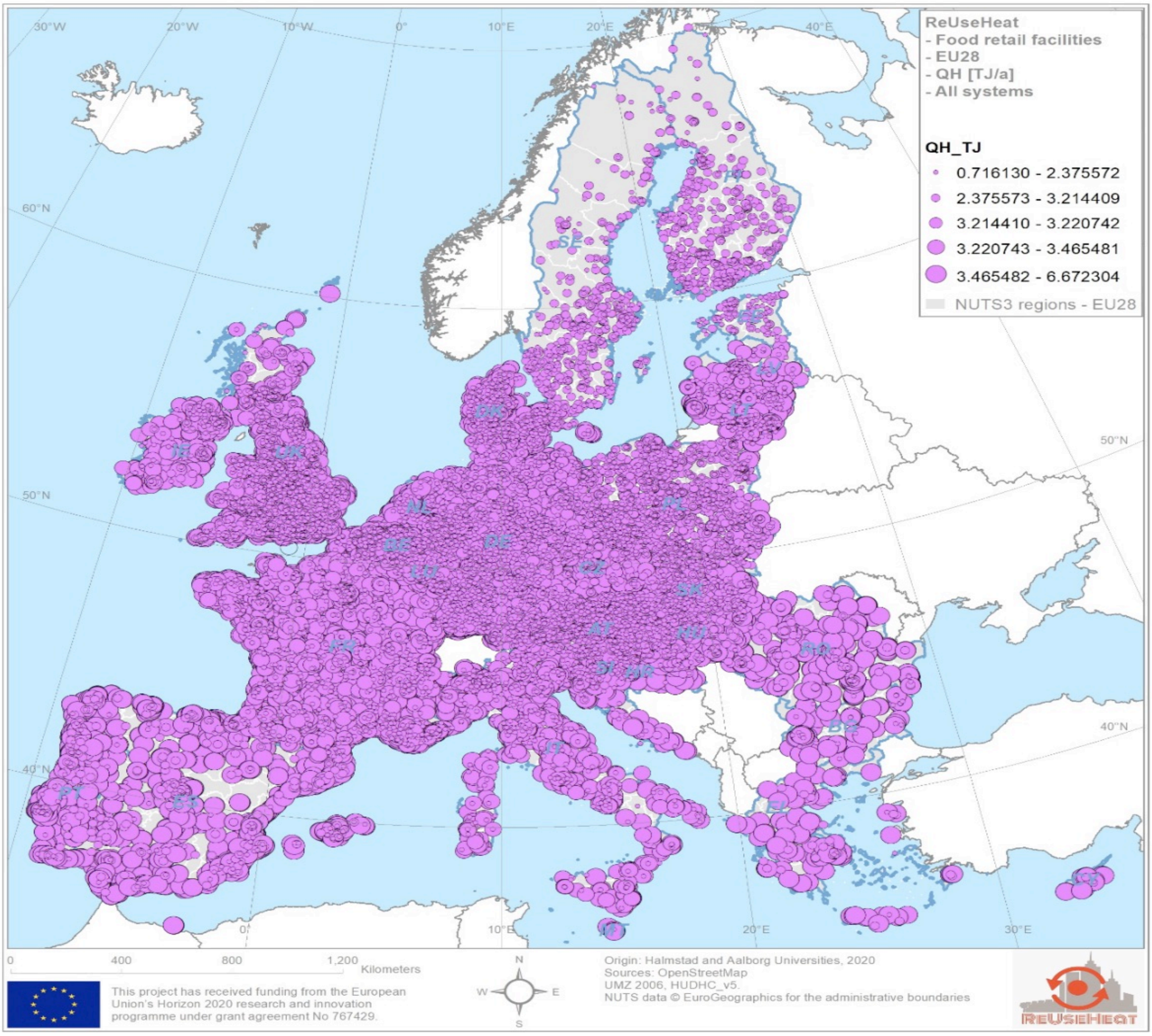
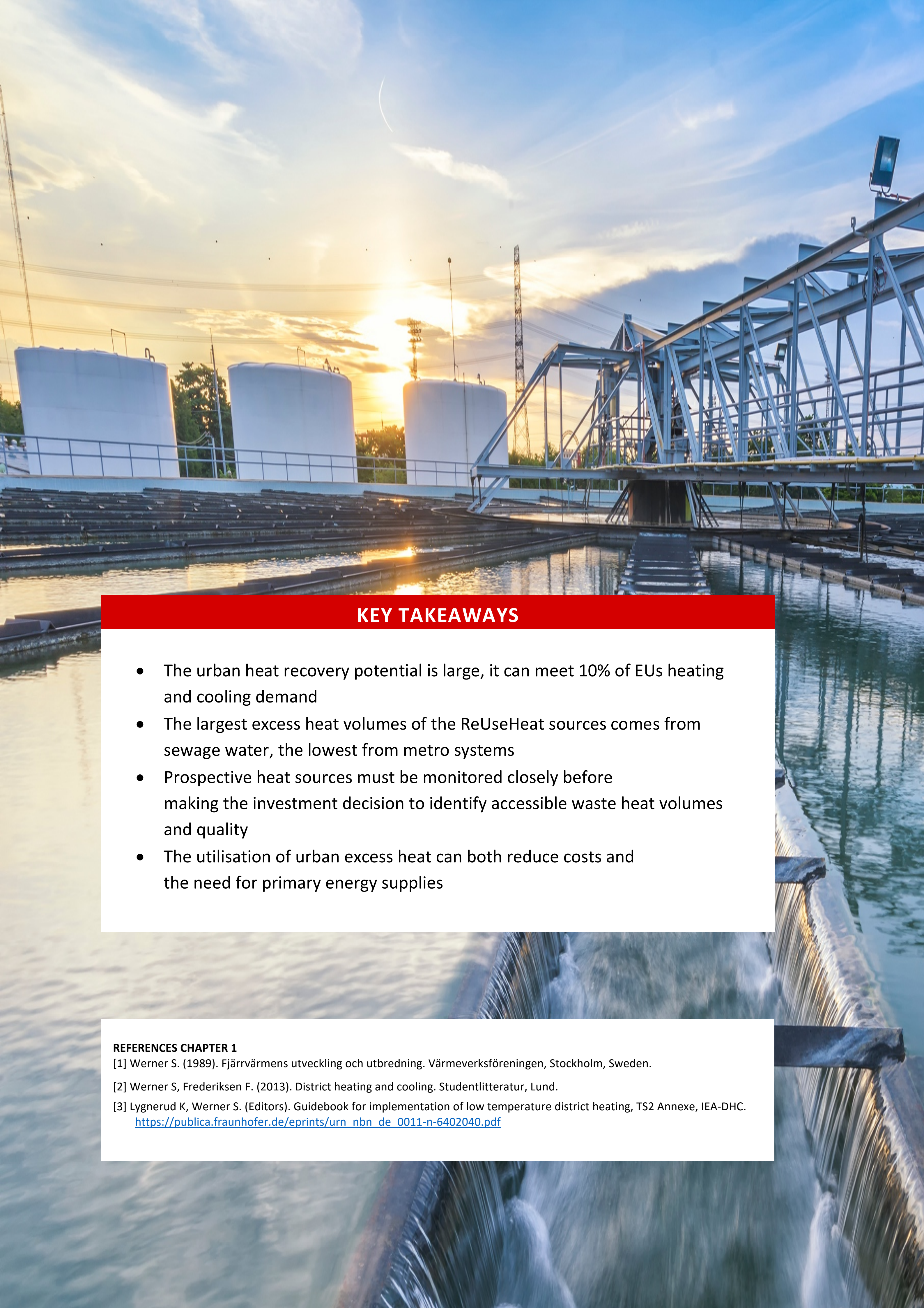


Figure 4. 41,832 EU-28 food retail store

1.2.6 Consequences of using urban waste heat

During the project, analyses of what would happen if the share of urban waste heat increased in the nations of the demonstration sites (Germany, France and Spain) were undertaken. For the full results, please see D1.5. Energy Planning Analysis. The analysis of the national capacity to assume low-temperature waste heat for heating purposes shows that:

- The utilisation of urban excess heat can both reduce costs and the need for primary energy supplies
- All sources can be feasible depending on the system in which they are used
- The availability of heat in winter defines how much can feasibly be utilised
- Heat pumps should be prepared to operate flexibly but can work as the baseload
- There is no significant difference in the feasibility of the ReUseHeat demonstrator heat sources



KEY TAKEAWAYS

- The urban heat recovery potential is large, it can meet 10% of EUs heating and cooling demand
- The largest excess heat volumes of the ReUseHeat sources comes from sewage water, the lowest from metro systems
- Prospective heat sources must be monitored closely before making the investment decision to identify accessible waste heat volumes and quality
- The utilisation of urban excess heat can both reduce costs and the need for primary energy supplies

REFERENCES CHAPTER 1

[1] Werner S. (1989). Fjärrvärmens utveckling och utbredning. Värmeverksföreningen, Stockholm, Sweden.

[2] Werner S, Frederiksen F. (2013). District heating and cooling. Studentlitteratur, Lund.

[3] Lygnerud K, Werner S. (Editors). Guidebook for implementation of low temperature district heating, TS2 Annexe, IEA-DHC. https://publica.fraunhofer.de/eprints/urn_nbn_de_0011-n-6402040.pdf

2. Business aspects

In the ReUseHeat projects work has been conducted to identify barriers to urban heat recovery (2.1), stakeholders, (2.2) risks-organisation-contracts (2.3) and characteristics of business modelling (2.4).

2.1 Barriers

2.1.1 Institutional barriers

Laws, policies, regulations and guidelines can disadvantage new technical systems and innovations (collectively defined as "institutional barriers"). ReUseHeat identified three main institutional barriers to urban waste heat recovery: the absence of a legal framework for waste heat, incentivised investments in renewables and the low maturity of the urban waste heat recovery systems.

The absence of the legal framework is a barrier because it creates uncertainty for potential urban waste heat recovery investments. Can an investment in waste heat recovery be interpreted as green as investments in established renewable techniques such as solar, wind or wave power? That established renewable solutions are incentivised through different forms of subsidies an additional creates a barrier for urban waste heat investments because a subsidised investment opportunity will be more appealing than a non-subsidised option with a longer payback period.

Urban waste heat recovery investments are system innovations encompassing unconventional heat sources from which heat is recovered using heat pumps. There is a low maturity level at the implementation level (amongst installers, fitters and welders), at the design level (the architecture of new buildings), at the heat source level (the owners of urban waste heat are not always aware that they could make use of the waste heat generated) and at the customer level (the awareness of the possibility to recover urban waste heat is low). Because of the low maturity, there is weak demand for heat recovery solutions. In turn, urban waste heat recovery is foregone throughout the chain, creating a "catch twenty two": there is no customer side demand- therefore it is not included in new construction or refurbishment – therefore it is not offered by installers.

Waste heat recovery is largely seen as part of district energy from the regulatory perspective and, as such, is subject to a wide range of regulations. Examples include:

1. Market regulation
2. End-user protection
3. Pricing regulation
4. Third-party access (TPA)
5. Energy efficiency and energy performance directives
6. Regulations relating to renewable energy
7. Building regulations
8. Tax exemptions and other financial incentives

The regulatory environment for waste heat can be improved in many ways. Foremost among these is the pressing need for low-temperature energy waste heat recovery to be treated as a renewable energy source. This is not universally accepted in part because of the disparity of treatment between domestic (micro) activity, which tends to be recognised as part of building regulation, and medium-scale production, such as for a large housing estate.

2.1.2 Other barriers

From ReUseHeat work it has been identified that there are other barriers than institutional to urban waste heat recovery. The first is the low technical maturity of the system. Low maturity is linked to a learning curve in terms of operational efficiency and installation costs. Furthermore, the risk associated with non-proven technology deters investment. Because of carbon not being priced in parity with its impact the payback period of urban waste heat is longer than 10 years which makes this kind of investment less attractive to the investor community. In terms of practical arrangement, the low maturity of urban waste heat recovery leads to a need to start contractual arrangement discussions from scratch. There appears to be a need for standardization of urban waste heat contracts. Least but not last the low level of maturity across the value chain leads to diverging views of the value of the waste heat. A standardization and categorization of what waste heat is would support in this kind of discussions.

2.2 Stakeholders

In ReUseHeat, we identified five key stakeholders in the urban heat recovery context. These are DH companies, urban waste heat owners, customers, investors and policy-makers. These stakeholders directly or indirectly affect the urban waste heat recovery value chain as depicted below. For the full analysis, please see D2.1 Stakeholder Analysis.

The idea that activities are important to understand the way that firms operate was first presented in 1985 [1]. Today, the activity-based view of firms is a widely accepted tool for assessing the firms' competitiveness. It addresses the value that customers perceive a product or service to have. The logic is that value activities unfold in stepwise chains or "value chains". Value accumulates at each step in the chain. The activities entail production activities, market interaction activities and delivery and support-related activities. The generic value chain encompasses value activities and margins (the difference between the total value and the collective costs of performing the activities).

A distinction is made between primary and supporting value activities. Primary value activities are needed to make the product whereas supporting value activities are needed to make the cycle from production to sales work. Value chains do not exist in isolation but are embedded in value systems consisting of a multitude of value chains up- and downstream. A generic value chain is given in Figure 5.

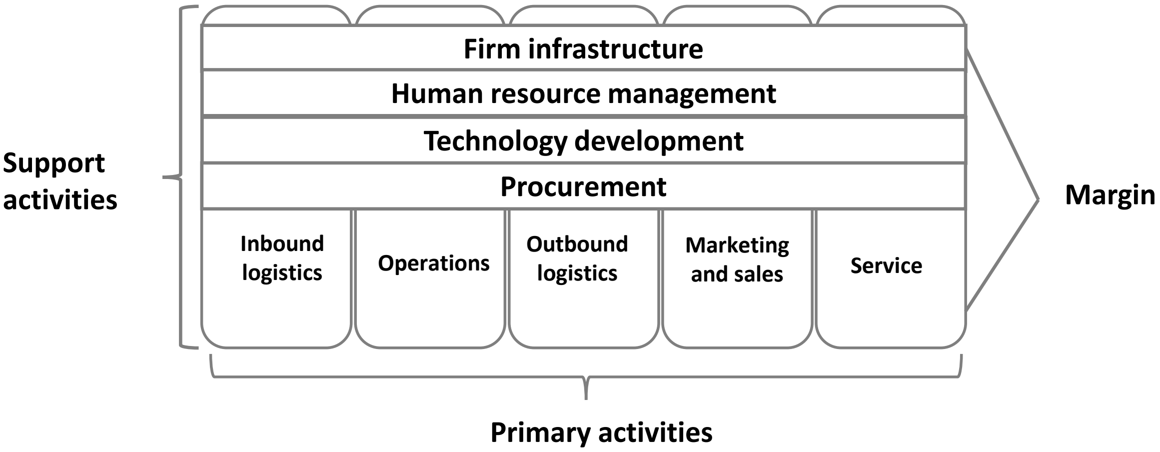


Figure 5. Value chain for district heating. Reproduced from [2].

The urban waste heat recovery value chain was identified by the partners in ReUseHeat. It is part of the value chain of DH and cooling (C) companies (DHC), supporting technology development. Because it is a support activity, the value chain of the urban waste heat recovery is incomplete (i.e., it has no support activities of its own but relies on the existing support activities of the DHC company). Mapping the primary activities is, however, possible.

Regarding the inbound logistics, the dialogue between the owner of the waste heat and the DHC company is the first activity. If the two parties agree to invest in the necessary equipment and can agree on long-term, stable heat delivery with an agreed value, then the next step is operations to secure the heat recovery and its delivery to the customers.
The operations will revolve around the usage of a heat pump, allowing low-temperature heat sources to be used in the existing DHN and often some kind of storage unit (buffer tank). Monitoring the heat recovery is another operational activity. These operational activities entail substantial communication between the heat owner and the district heating company.

Outbound logistics are the delivery of the heat to the customers. In the ReUseHeat demonstration sites, the existing DHNs will be used, hence the urban waste heat recovery value chain piggybacks on the existing infrastructure of the DHC companies, creating a synergy for the DHC company when engaging in urban waste heat recovery. The value chain regarding marketing, sales and services is not yet developed and the activities of the DHC company will be used. When the product matures, marketing and sales specific for urban waste heat recovery can be developed. The value chain of urban waste heat recovery is specific in that the customer dialogue is extensive and revolves around a tailor-made prosumer solution. It is also specific in that it is not supported by any specific legal framework or any targeted incentives.

The role of the DHC company stakeholder is to develop the urban waste heat recovery solution by completing its value chain to make it a profit-generating business venture. Important components are efficient marketing and sales, making the customer aware of the value to be gained by consuming urban waste heat. On the supply side, the heat supplier – the stakeholder owning the urban waste heat –

must be willing to supply the heat on an ongoing basis and at an agreed-upon price. In addition to this conventional supplier role, the waste heat owner must disseminate information about heat recovery to raise awareness of the process.

The investors and policymakers do not have any direct role in the value chain of urban waste heat recovery but can facilitate market uptake and acceptance of these solutions by providing the right kind of incentives (e.g., incentives to invest in heat recovery schemes by offering beneficial loan arrangements and subsidies to urban waste heat recovery investments).

ReUseHeat's key finding is that urban waste heat recovery expansion is not about developing new technology. Instead, the stakeholders need to collaborate in new ways to disrupt the current limiting conditions and realise the potential of urban waste heat recovery.

2.3 Risk – organisation – contracts

2.3.1 Risk

Risk can broadly be defined as a scenario in which losing something of value is probable. The item of value can be wealth, time, health or anything else that can be assigned a value. To prioritize amongst risks a risk score is often computed addressing the gravity of a risk if it occurs. The risk exposure is computed as per Equation 1 below. More formally, the risk exposure of an individual item is usually defined as illustrated in Table 3, this kind of risk exposure matrix was applied on an ongoing basis during the ReUseHeat project, for all four demonstration sites. The intent was to capture any risks, to mitigate them and follow up on the effectiveness of the corrective measures applied.

$$Risk = Gravity\ x\ Probability \qquad (EQ.\ 1)$$

Table 3. Risk matrix.

Risk Priority Matrix (P x G)		**Probability**			
		Low - 1	Moderate - 2	High - 3	Very high - 4
Gravity	Very high - 4	4	8	12	16
	High - 3	3	6	9	12
	Moderate - 2	2	4	6	8
	Low - 1	1	2	3	4

The size of the risk exposure can be interpreted as its expected impact. This section will discuss risk in the context of DH projects. Each demonstrator reported several risks during the project. Although information regarding which demonstrator reported the risk, details of that risk and the overall assessed size of the risk are confidential, an anonymised selection of representative risks in urban waste heat recovery projects is given below. The identified risks have been divided into the two categories: Authorization processes, and implementation process.

Authorization processes

This category of risk impacts tendering and permitting stages. Permits for new heat recovery schemes can be exhaustive processes that take time. Furthermore, the absence of legal waste heat standards intensifies the urban waste heat challenge. Based on the ReUseHeat experience a list of "to do" and "not to do" was drafted on the topic of authorization. The "to do" are listed first (for more details please review D3.8).

To Do

- Involve all stakeholders and local authorities from the beginning of the project, including the conceptual design phase
- Ask for clarifications to the relevant authorities before the official application (if feasible) to avoid issues in the permitting phases
- Carefully design installations accounting for potential constraints related to the access of the heat source, technology and heat demand
- Identify a project site where the excess heat source sufficiently close to the user to avoid long and costly transmission lines
- Consider more project alternatives then one to have a backup option in case of issues

- Perform sensitivity analysis on technical and financial parameters

Not To Do

- Underestimate time and effort required for authorization process
- Provide insufficient technical details in the permit application, assuming basic knowledge is available to all authorities (it is not)
- Focus on the heat source only and not on the availability of heat users and on the related constraints
- Define a contract or business model that is profitable for only one of the parties (it must be a win-win)

Implementation

As the long list of risks demonstrates, there are many technical aspects to consider when recovering waste heat. The risks also apply to waste heat recovery from urban sources. In ReUseHeat the technical risks have all been overcome and it is concluded that technical aspects do not constitute the main hurdle for urban waste heat recovery. Below, a list of implementation-related difficulties are listed. The list is based on previous work [3] and experiences from ReUseHeat demonstrator implementation.

1. Overly optimistic estimates of project lifetime
   (known risk from earlier installations, also identified in ReUseHeat)
2. Overly optimistic budgeting
   (known risk from earlier installations, also identified in ReUseHeat)
3. Unforeseen technical difficulties from the novelty of the project
   (known risk from earlier installations, also identified in ReUseHeat)
4. Oversizing of the system
   (known risk from earlier installations)
5. Insufficient users signing up to the solution
   (known risk from earlier installations)
6. The heat source ceases to provide excess heat
   (known risk from earlier installations)
7. Delays in the availability of the heat source, resulting in failures to supply end-users
   (known risk from earlier installations, occurred in ReUseHeat but installed peak load/backup facility was covering this topic)
8. Heat pump malfunctions or inefficiency
   (known risk from earlier installations, occurred in ReUseHeat where there was a shortage of water to the heat pump due to a closed circuit in the hospital installation and a bypass installation in the datacenter heat pump to handle too high return flow temperatures)
9. Failure to sufficiently monitor project
   (known risk from earlier installations)
10. Exceeding local noise regulations
   (known risk from earlier installations, was an issue in the design phase of the first hospital demonstrator installation: would have been solved with a sound-proof cabinet)
11. Excess heat is at a lower temperature than expected
   (known risk from earlier installations)
12. Delays in receiving materials or equipment
   (known risk from earlier installations, one of the demonstrators took this into account and acquired all necessary material and equipment early on in the project to have access to it when it was to be installed)
13. Problems integrating the heat source into the existing network
   (known risk from other projects)
14. Lower heat pump performance than expected
   (known risk from other projects)

2.3.2 Organization

DH ownership is an interesting parameter to investigate to understand contracts and business models in urban waste heat recovery. The preconditions will differ significantly between privately or publicly owned investments. Two Swedish reports, [2] and [4], account for different forms of ownership in DH but, in summary, DH companies can be owned by a private party, a municipality, the state or various combinations of public and private parties.

Urban waste heat recovery investments are likely to be undertaken between two private parties (if the waste heat provider and DH company are privately owned) or between a private party (the waste heat provider) and a public party (the DH provider). Urban waste heat recovery investments will likely be undertaken in countries in which there is knowledge and precedents of industrial waste heat recovery. Out of the EU-28, Sweden and Germany recover the largest volumes of industrial waste heat [3]. Both markets are mature heat markets characterised by widespread municipal or regional ownership of district heating companies. Hence, public-private partnerships (PPP) are presumed to be the most relevant framework for designing efficient contracts for urban waste heat recovery. There are many standardised PPP contracts (please see D2.3 Contractual Forms for details).

The PPP solution is common in mature district heating markets. This is, for example, the solution of the German ReUseHeat demonstrator (data centre heat recovery). In markets that are new to district heating, private solutions are more frequent. For example, the growing UK market is particularly inclined to private ownership. Based on an in-depth study by The Carbon Trust, a not-for-profit private company that aims to help organisations reduce their carbon emissions, relevant ownership models for DH, in particular, have been identified. More information about these ownership models is presented in Appendix 1: Private ownership forms for district energy – the UK experience.

An energy service company (ESCO) is another form of collaboration found in district energy. ESCOs are companies set up to supply energy or deliver energy savings. ESCOs can be commercial, i.e., for-profit, or non-profitmaking and aim to provide a public service. An ESCO can be owned by a single party or multiple parties in the public or private sectors. Often, ESCOs are jointly owned by public and private sector companies and are thus an example of a public-private partnership. An energy performance contract (EPC) is a contract for delivering energy efficiency savings to businesses that cannot fund them themselves. The energy service can be provided by an ESCO. Under an EPC, energy efficiency improvements are made by the provider and the client repays the cost using savings resulting from the increased energy efficiency. The service provider often guarantees the level of efficiency savings, thus reducing the risk to the client. This is the case at one of the ReUseHeat demonstration sites (the hospital).

2.3.3 Contracts

Turning to the contractual aspect of urban waste heat investment, waste heat recovery projects often require the involvement of multiple parties. Particularly, the waste heat owner, the energy company and the end user are usually (but not always) separate entities. When this is the case, contractual arrangements are required between parties to formalise their relationships. There are many potential contractual arrangements in waste heat recovery. At ReUseHeat, each of the following arrangements (Table 4) are in place for at least one of the demonstrator projects:

Table 4. Parties in contractual arrangements.

Primary entity	Partner
Energy company	Waste heat suppliers
Energy company	End user
Energy company	Housing developer
Energy company	Academic institution (model developer)
Energy company	Heat pump supplier

Some of the above arrangements, like that between the energy company and the end user, are well established and, therefore, standard contracts can be put in place. Other arrangements are specific to pilot projects. For example, once the technology is established, the role of academic institutions will likely be reduced. Similarly, heat pump suppliers will likely play less of a role in installation and operation when the technology is more mature. By far the most important contractual arrangement is that between the energy company and the waste heat supplier (often a prosumer). This relationship must be solid to minimise the risk of a cessation of supply.

It is useful to think of contracts as tools for the allocation of risk and reward. Different types of arrangements allocate risk and reward differently and well-written contracts should aim to allocate the risk to those parties who are most willing and able to adopt it.

An example of how contracts determine risk allocation is in the contract between the waste heat supplier and the energy company. If the latter pays a fixed fee to the former for the use of its waste heat (regardless of how much it needs), it is vulnerable to large drops in demand because it still has to pay the heat supplier the same fee. If, on the other hand, the energy company pays per unit of waste heat it requires, some of that risk is allocated to the heat supplier. Of course, greater risk should entail greater rewards and the price the waste heat supplier receives should reflect this balance.

In the light of volatile electricity prices, it is important to have a contractual arrangement allowing the win-win for engaged parties to continue with the heat recovery. If, for example, a datacenter, that uses a lot of electricity for cooling, would be better off to release the waste heat into the ambient air rather than investing in electricity for pumping the waste heat to the DH company there must be a clause in the contract that fairly distributes the added cost when electricity price is high. An alternative is that the datacenter can disregard the requirement of delivery of waste heat when the electricity price is above a certain pre-determined level.

Based on identified risks in ReUseHeat, several important factors to consider when designing urban waste heat recovery contracts were identified (Table 5). A guide to writing heat supply contracts was also developed (D2.3) and is provided in Appendix 2 of this book “Guide to writing heat supply contracts”.

The first factor is low maturity of installation which drives engineering and operational risk as well as a disinterest from investors.

The second factor is that there is no legal framework in place. This drives risk as it is unknown if waste heat is to be considered as a renewable or not. Furthermore, lacking legislation does not support standardization of contracts or implementation.

The third factor is that the value of waste heat is subjective. The two parties involved in the contract need to agree on value, volumes and contingency measures to take in the case of one party not respecting the contract. Further complicating the matter is the fact that for one party the waste heat provision is not core business whereas it is for the other party.

The fourth factor is that the payback time is long. Urban waste heat recovery has a green carbon footprint but with current valuation of CO2 it is not a solution that investors would find relevant and within an acceptable payback timeframe.

The fifth factor is asymmetric information. It reflects that waste heat recovery necessitates the integration of processes of two different organizations. Doing so it is important to inform the other party on how operations are usually performed to avoid misunderstandings and mistakes in the heat supply.

The sixth factor is shared incentives. Urban waste heat recovery will be undertaken when it generates a gain for both parties involved. If there is no shared incentive or gain it is unlikely that the collaboration will be long term.

The seventh factor is the risk that the heat source is terminated. This is an unpleasant reality and should be accounted for already at contractual stage. It is important that there is a contingency plan the day the heat supply ceases.

To summarise ReUseHeat findings on contractual writing, the main barriers to the bankability – and thereby contract writing of urban waste heat recovery projects are related to the low experience level of urban waste heat recovery amongst key stakeholders which adds risk to the investment.

Table 5. Factors for designing contracts on urban waste heat recovery.

Factor	Comment
Factor 1: Low maturity of installations	The technical viability of urban waste heat recovery investments must be validated. The fact that the system innovations are not yet proven is a barrier to investment. The unproven solutions are characterised by both engineering and operational risks.
Factor 2: No legal framework in place	The lack of uniform legislation for waste heat overall and urban waste heat, in particular, is a barrier in that it prevents installations and contracts from being standardised. This drives risk and offsets investment. In addition, there are no demand-side incentives for urban waste heat and there is low awareness of urban waste heat recovery as an option. This contributes to low demand for urban waste heat recovery solutions.
Factor 3: The value of waste heat is subjective	Waste heat comes from processes that are not the core business of the heat-generating industry. This limits interest and understanding of recovery and DH processes from the heat-generation side. The waste heat recovery arrangements need to be win-win solutions.
Factor 4: The payback period is long	Payback is an important KPI for investors as long paybacks are associated with external risks (demand risk, regulatory risk, political risks and competition). Long paybacks such as those in ReUseHeat constitute an investment risk.
Factor 5: Asymmetric information	Investors have a shortcoming in terms of district heating and urban waste heat recovery in particular. There is, for example, a lack of competence among investors to perform efficient due diligence.
Factor 6: Shared incentives	Shared incentives can be established in long-term, mutually beneficial contractual arrangements. This can be an advantage when entering urban waste heat recovery contracts. Often, there is a shared incentive to reduce CO_2.
Factor 7: Termination of heat recovery	The risk of non-heat delivery is important to address in any waste heat recovery scheme. It is possible to contractually determine what happens if the recovery is terminated or there is a temporary outage.

Further on the note of bankability, it was identified in ReUseHeat that the demonstrator sizes were too small to motivate a bank to engage in a due diligence process before investing. It led to the conclusion that scaling up urban waste heat recovery investments necessitates bundling of urban waste heat recovery investments to make them bankable.

The implementation of pilot projects, as in the case of ReUseHeat demonstrators, primarily aims to demonstrate the technical feasibility of solutions to recover heat available at the urban level from several different sources and prove the projects' economic profitability by evaluating their capacity to operate as expected, guaranteeing the cash flow to repay bank debt. Moreover, these demonstrations allow the collection of real monitored data at all project phases, from the design and permitting stages to procurement, construction and installation and the real system's operation period, thus generating technical and non-technical knowledge for all stakeholders involved and simplifying the replication of this kind of project even from a bankability perspective.

The implementation of pilot projects does not necessarily imply the financial support of public entities; many urban waste heat recovery investments are profitable without incentives and first-of-a-kind projects may be realised by utilities with internal funds or by resorting to corporate finance instead of project finance. This would create a track record of similar projects that could be used to request project financing for subsequent, similar investments and is especially useful for utilities managing a DH network that are willing to exploit urban waste heat in more than one location. Generally speaking, it is also worth highlighting that the involvement of utilities is a plus in the bankability assessment; these companies are considered reliable as they are experienced in the energy sector and the same urban waste heat recovery project has a higher probability of acquiring funding if promoted by a utility rather than, for example, the waste heat owner.

To improve the legal framework, a top-down insertion of the exploitation of urban excess heat sources in the EU and national strategies and, subsequently, in plans made by regions and municipalities would increase knowledge about these opportunities and generate easier, faster and more standardised permitting processes. This would reduce the risk associated with these projects by limiting possible delays. The involvement of the public sector, especially at the local scale – e.g., municipalities – in the realisation of urban waste heat recovery project financing increases the bankability of the projects not by reducing the intrinsic project risks but by increasing the equity provided by project proponents and reducing the fraction of the investment covered by debt.

To dedicate incentives or public funding schemes for urban waste heat recovery projects, a proposal for a credit facility including a public guarantee was suggested by ReUseHeat (D2.2).

2.4 Business modelling

Regarding business models, work was undertaken in the project to document and analyse the business models of the demonstrators. The business model canvas [5] was used as the model of analysis. It provides a framework of nine blocks and is widely used to understand business models. It was developed jointly by academic researchers, government officials, professionals from different industries, analysts from different sectors and consultants interested in business modelling. The canvas has been selected for ReUseHeat as it is a framework that explicitly addresses the components deemed relevant for understanding business changes in district heating.

The canvas is illustrated in Table 6. Four of the blocks address the customer, outlining the customer segment, the channels used to reach customers, customer relationships and the value proposition. Three of the blocks consider activities undertaken to deliver the value, the resources needed for value creation and the imperative partnerships to deliver the product or service. The last two blocks outline the cost structure and the income structure.

Table 6. The business model canvas framework.

Key partnerships	**Key resources**	**Customer value**	**Customer segment**
"Who can help you"?	"What you need"?	Anwers the question of "what do you do"? This is where the analysis starts	"Who do you help"?
	Key activities	**Customer channel**	**Customer relationship**
	"How do you do it"?	"How do you reach them"?	"How do you interact"?
Cost strucure		**Customer structure**	
"What will it cost"?		"What will it cost"?	

First, by reviewing the customer value of the demosites, we see that the value of green energy/ low carbon footprint is one of the key drivers for the demonstration site partners engaging in the ReUseHeat project. All recognise the added value of green energy that can be offered to customers with the urban waste heat recovery. A low carbon footprint can ameliorate the company brand but also offer customers DH without extending the heat production capacity of the central production unit. In the case of BS|ENERGY, the end customer is not directly informed that there is an additional "green" component compared to the (until 2022 mostly) conventional CHP production in the main network. In the case of ASIME, the shift from gas to a green solution is known by and agreed to by the customer. The foreseen metro operator would have benefitted from replacing electrical heating with green energy which would substantially have reduced CO_2 emissions. For the awareness creating demonstration site, the dashboard will showcase the value of green energy. In summary, the value of offering green energy is an additional value in the urban waste heat recovery investment compared to the conventional DH business model. Over time and with a future roll-out of the concepts, the value of green could serve to differentiate the DH portfolio.

The green value is important to cities, politicians and the companies engaged in heat recovery, but it is not yet in explicit demand from customers. A further note on the topic of customer value, is that in ReUseHeat, heat and hot water are not offered as a service. Instead, the conventional offer of heat and hot water remains (three of the demonstration sites: data centre, metro, hospital). A cooling service for data centres could have been an efficient service offer for BSE and offering indoor climate control could have been an alternative approach for OPES. This may be an offer in the future. The energy service provider ASIME provides energy efficiency services related to the heating and cooling of the hospital. However, the offer is still presented as energy-efficient heat, cooling and hot water rather than an "indoor comfort service". The dashboard provides a service to DH system operators that they can provide to their customers (building owners) who will be interested when the end user expresses a demand. EDF is detecting a demand for this kind of transparency towards the end user in procurement processes and believes that this kind of data could become standard in future energy arrangements to encourage energy citizens. The demand for services as offered by the dashboard remains partially unknown, nor is there a clear demand for it from end users at the other demonstration sites, but it indicates that energy related services are likely in the future district energy sector.

Second, addressing the customer relationship, a close customer dialogue and relationship are necessary for urban waste heat recovery success. This can be a window of opportunity for DH providers in an energy context that is becoming more digitised and increasingly distant to the end user. With a hands-on, tailored offering, the urban waste heat recovery investment can lead to a long-term loyal customer base. Indeed, future district energy providers will need to offer an array of tailor-made business models rather than one base case that fits all. The customer segment in traditional DH business cases is an owner of a building (often it is business to business arrangement). The demosites in ReUseHeat encompass a municipal customer which is a prosumer (a hospital), a construction company (over time this contract is planned to be transformed into a contract with tenants heated by the datacenter waste heat), a building owner (B2B) or municipality (for the dashboard) and a municipal customer which is a prosumer (metro operator). The spread of potential customers of urban waste heat installations reflects that there is a need to consume the heat close to its source which increases the likelihood that the customer is also a prosumer.

Third, the owners of waste heat are key partners for urban waste heat recovery. The owners of urban waste heat are often local, and the heat volumes are limited. Engaging in contracts with them necessitates a shift in business logic on the district energy provider's side: placing a value on local, decentralised heat sources. This necessitates a business logic shift from large-scale production and distribution from a central node towards a system with less emphasis on centralised production and increased prioritisation of decentralised distribution.

Regarding resources, activities and partnerships, the urban waste heat recovery business often means that a system needs to be established, which includes a heat source and a heat pump or heat exchanger. An important resource in the low-temperature system will be heat pump/s. In addition, it is important to control the system and effectively include a number of heat sources of varying size and temperature. Control and operation of the system, including storage, are important activities. To secure access to the heat source, a dialogue is required with the actor who owns it. It is, just as in the context of high-temperature residual heat, important to enter into effective contracts with the owner of the urban waste heat. To understand the quality and availability of the residual heat source and the needs of the owners of the waste heat source, requires a close dialogue. The kind of human resource that can engage in customer dialogue around a tailor-made solution is required for the urban waste heat recovery. By providing such a resource, the energy company can enter long, mutually favourable, contracts where the residual heat producer becomes an important partner.

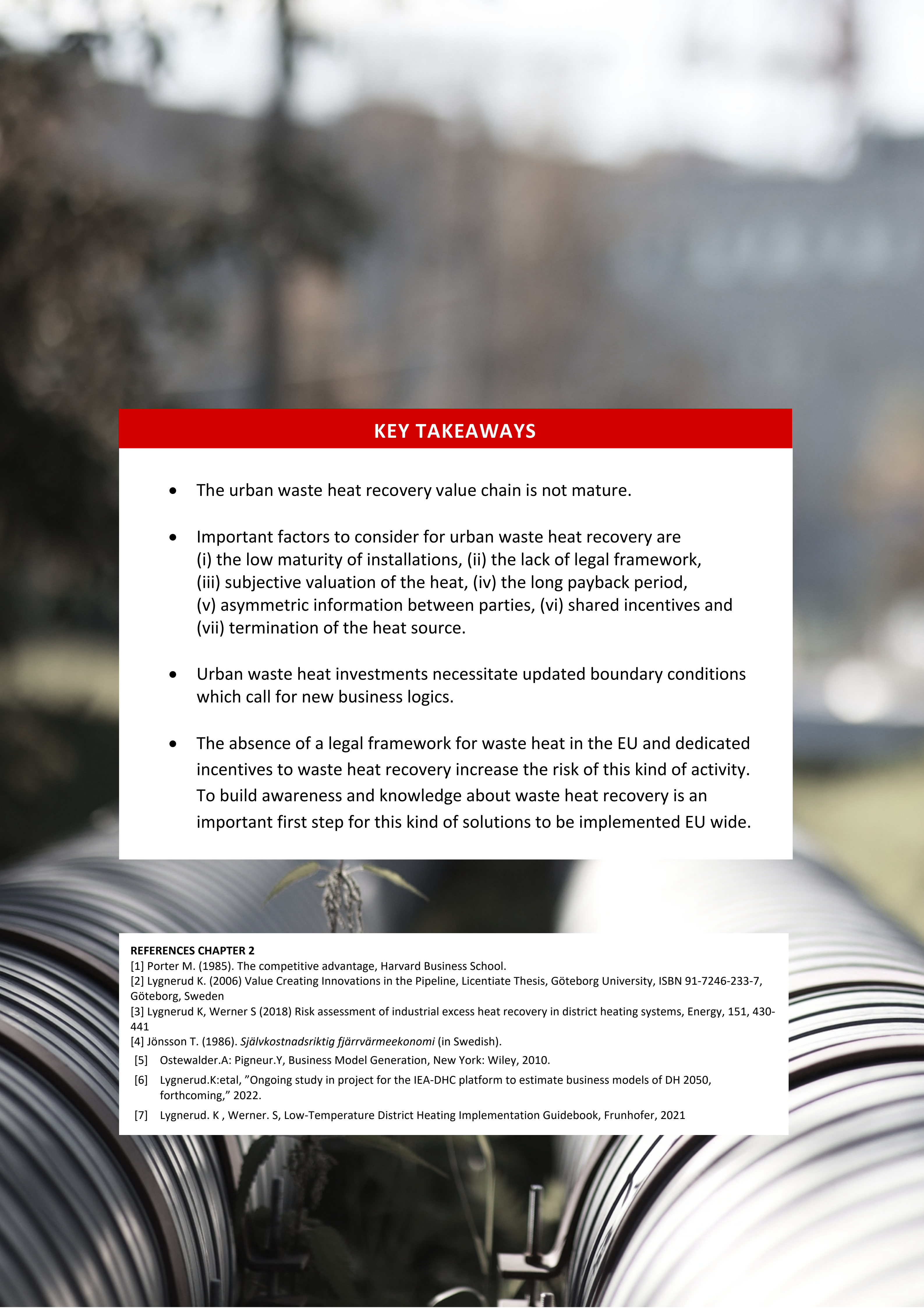
The results that are seen on the cost side reflect the above-mentioned resource additions. The green value in the customer offering can form the basis for a strategy in which the energy company differentiates prices. Customers who receive heat from a local residual heat source could pay a premium price for this. Studies on the customer's willingness to pay more for a green residual heat source have shown that there is a willingness to pay in the range of 5-20% as a mark-up on the current price [6].

It has been identified that when implementing low-temperature waste heat recovery today, the energy companies tend to ensure technical functionality and not change the business model that is applied. This results in values that the energy companies have could have harvested remain unharvested. This approach is probably due to the fact that there is a tradition among energy companies to start from technology and ensure that it works. Therefore, the opportunity is not taken to establish a sustainable technical and economical solution for the urban heat recovery in tandem, although it is possible to do so. An offer that is a combination of the high-temperature offer and a low-temperature offer can strengthen the district heating's attractiveness and thereby competitiveness, further confirmed in [7].

In connection with discussions about business models, it is important to address risk. Regarding operational risk, a decentralized energy system means that dependence on the central heat source is reduced, which creates a resilient system. The decentralized system requires effective control and thus increases the impact that inefficient control has. Regarding the heat source, it is important to carefully investigate it before initiating the residual heat recovery. It is important that its size and quality (temperature level) is known and that the contract established with the residual heat owner is of such a nature that it can be updated to handle changes and that it includes clauses for handling deviations. Entering into a partnership with a residual heat source means establishing dependence on another organization's processes, which requires a good dialogue with the residual heat supplier's and its own organization's staff: an additional factor to consider when writing a contract.

A risk that is addressed in connection with high-temperature residual heat recovery is that the heat source disappears by e.g. industrial activity ceases [3]. This risk also exists for low-temperature residual heat sources. However, it has been shown that some low-temperature sources are more stable and long-term than others. As an example of each side of the spectrum, residual heat from urban infrastructure can be taken, such as heat from wastewater or heat from metro systems compared with residual heat from data centers or grocery stores. The city's infrastructure is in itself long-term and the residual heat generated from it is stable. Data centers in an urban environment tend to be moved after 10-15 years as the part of the city where they are located will be used for new construction of e.g. residential properties. Similarly, grocery stores can be relocated.

Finally, it is relevant to note that residual heat recovery from urban heat sources is a new phenomenon in the district heating sector. The novelty is to establish systems which include one or more low-temperature residual heat sources and one or more heat pumps. It is not residual heat recovery, nor the technology used in the heat pumps that is new but the combination of the two. In Europe today, there is no framework that determines what residual heat is. Is it to be equated with renewable energy types? This uncertainty about what it is you are investing in and whether it is judged to be a long-term sustainable system or not. In addition, it is not uncommon for support to be available at regional, national or EU level to invest in renewable energy: something that creates an uphill battle for the low-temperature, non-subsidized, business model.



KEY TAKEAWAYS

- The urban waste heat recovery value chain is not mature.
- Important factors to consider for urban waste heat recovery are (i) the low maturity of installations, (ii) the lack of legal framework, (iii) subjective valuation of the heat, (iv) the long payback period, (v) asymmetric information between parties, (vi) shared incentives and (vii) termination of the heat source.
- Urban waste heat investments necessitate updated boundary conditions which call for new business logics.
- The absence of a legal framework for waste heat in the EU and dedicated incentives to waste heat recovery increase the risk of this kind of activity. To build awareness and knowledge about waste heat recovery is an important first step for this kind of solutions to be implemented EU wide.

REFERENCES CHAPTER 2

[1] Porter M. (1985). The competitive advantage, Harvard Business School.

[2] Lygnerud K. (2006) Value Creating Innovations in the Pipeline, Licentiate Thesis, Göteborg University, ISBN 91-7246-233-7, Göteborg, Sweden

[3] Lygnerud K, Werner S (2018) Risk assessment of industrial excess heat recovery in district heating systems, Energy, 151, 430-441

[4] Jönsson T. (1986). *Självkostnadsriktig fjärrvärmeekonomi* (in Swedish).

[5] Ostewalder.A: Pigneur.Y, Business Model Generation, New York: Wiley, 2010.

[6] Lygnerud.K:etal, ”Ongoing study in project for the IEA-DHC platform to estimate business models of DH 2050, forthcoming,” 2022.

[7] Lygnerud. K , Werner. S, Low-Temperature District Heating Implementation Guidebook, Frunhofer, 2021

3. Findings from demonstration sites

In this chapter, the concepts of urban waste heat recovery for the four demonstration sites included in the project are provided. First is waste heat recovery from the data centre (3.1). Next is the waste heat recovery from the cooling towers in a hospital (3.2). Third is the foreseen metro heat recovery (3.3). Fourth is the awareness creating demonstration (3.4). In the project analyses on replicability and scalability were performed (3.5) as well as on external replication, these experiences are presented last (3.6).

3.1 Data center heat recovery

3.1.1 Introduction

Veolia's subsidiary, BS|ENERGY, owns and operates the DHN and the supplying power plants in Braunschweig, Germany. With its 263km central DHN in Braunschweig, BS|ENERGY serves 8,000 heat customers or about 56,000 houses and apartments as well as commercial and municipal buildings, supplying approximately 45% of the city's heat demand. On average, about 804 GWh are sold per year. The average peak heat demand amounted to 320 MW in recent years. Heat is generated centrally at two CHPs in the town centre (Mitte) and northern suburbs (Nord). The plants feature four generation systems and there are two peak boiler stations in the southern (Süd) and western (West) suburbs. Please, see the map in Figure 6, below.

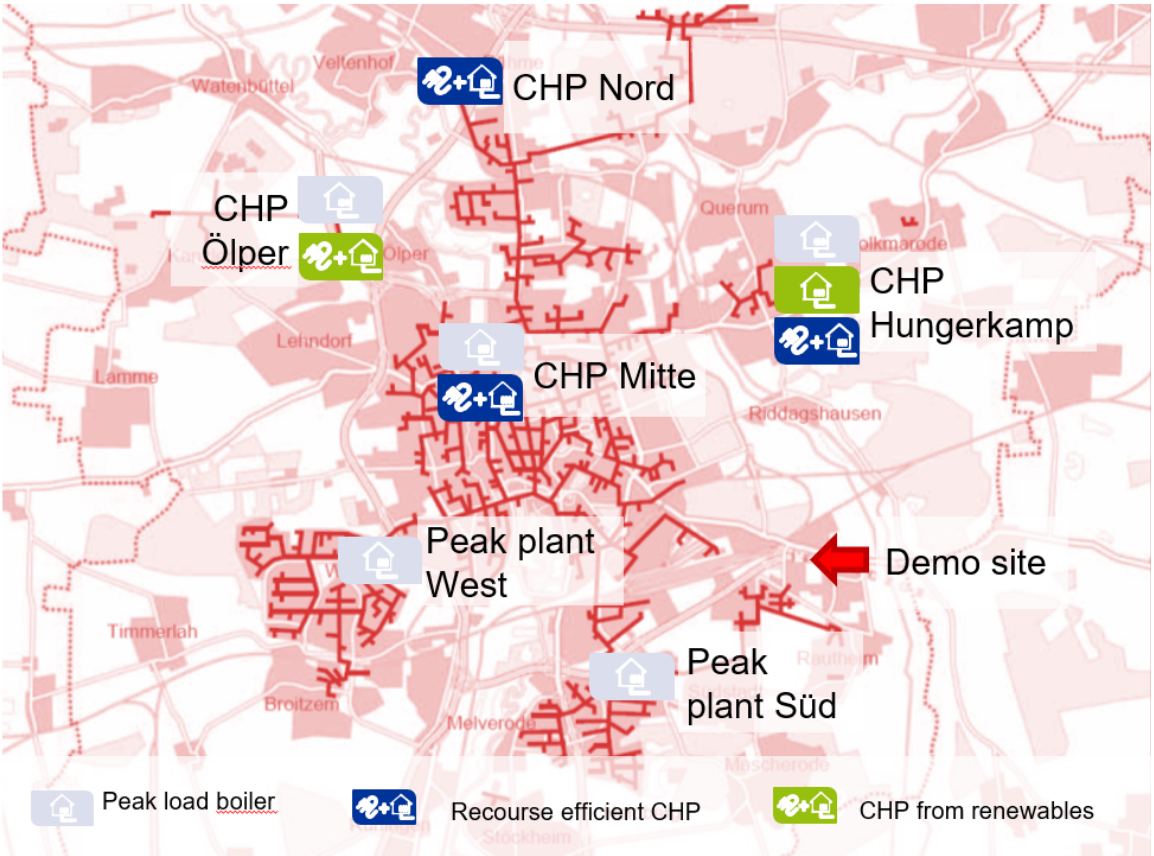


Figure 6. District heating network in Braunschweig.

A local property developer requested DH during the early planning phase of a new residential area. With the simultaneous construction of a new data centre in the adjacent parcel, Veolia identified this as an opportunity to develop an innovative DHN that would use the waste heat from the MW-sized cooling system of the IT infrastructure. Extracting heat from the data center reduces the need to cool it and the associated energy consumption. This became one of the ReUseHeat demonstration sites.

The main challenge was the low temperature of the waste heat. Therefore, several steps had to be taken: First, a heat pump was used to increase the temperature of the heat. Second, a new DHN had to be built and operated at a low temperature (Low-Ex, 4th generation). Third, the customer supply for space heating and domestic hot water had to use solutions to deliver the required building services at low temperatures and ensure a low return temperature. Fourth, all systems had to communicate with each other such that the whole system could operate efficiently without compromising the level of service. To meet these requirements, state-of-the-art monitoring and control solutions were needed. Together with a heat storage unit, the system can adapt to variable heat demand.

The benefit of the installation is that a new area can be heated by waste heat through a low-temperature system. This is an important step for BSE in its transition towards a greener heat supply. The low-temperature solution allowed BSE to expand its heat supply without investing in additional conventional heat equipment.

3.1.2 Concept

BSE demonstrates an advanced solution based on heat recovery from a data centre associated with a low-temperature (LT) DHN. Instead of discharging the excess heat from the data centre to the ambient air, it is injected into a LTDHN. Before the injection, a heat pump must raise the temperature of the excess heat from about 25 °C to 70°C. By supplying energy for space heating and domestic hot water in a nearby housing area and a commercial area, the LTDHN water is cooled and returned after use to the heat pump to be reheated. By extracting heat to use in the heating side of the system, the heat pump lowers the temperature of the cold-water cycle in the data centre at the same time. This reduces the need to cool the data centre and the associated energy consumption. The conceptual design is illustrated in Figure 7.

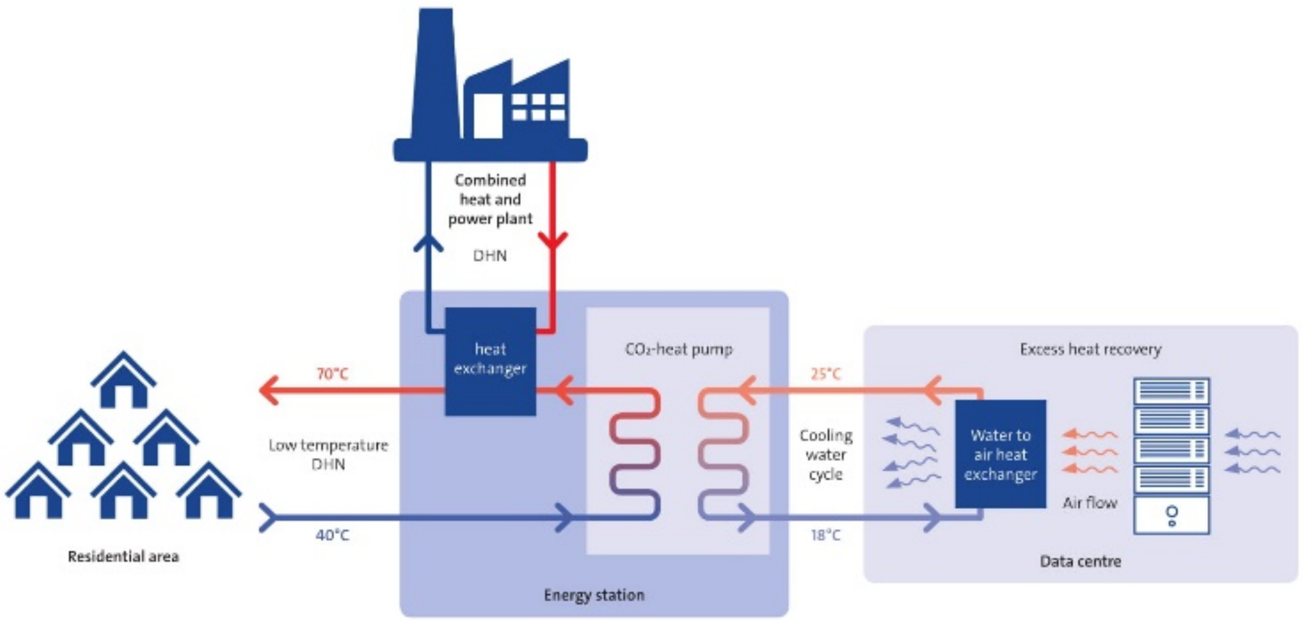


Figure 7. Data centre waste heat recovery concept.

By using a LTDHN, losses can be lowered to less than 10% and the heat pump's efficiency can be increased as it is directly correlated to the temperature difference between the heat source (data centre) and the heat sink (heat network). Furthermore, the heat pump will use CO_2 as a working fluid to ensure the system's sustainability. This refrigerant combines the lowest possible global warming potential (GWP) with non-toxicity and nonflammability. The area to which the heat is supplied comprises 400 residential units. In addition, two commercial units will be connected to the LTDHN, including a supermarket. The layout of the area is presented in Figure 8.

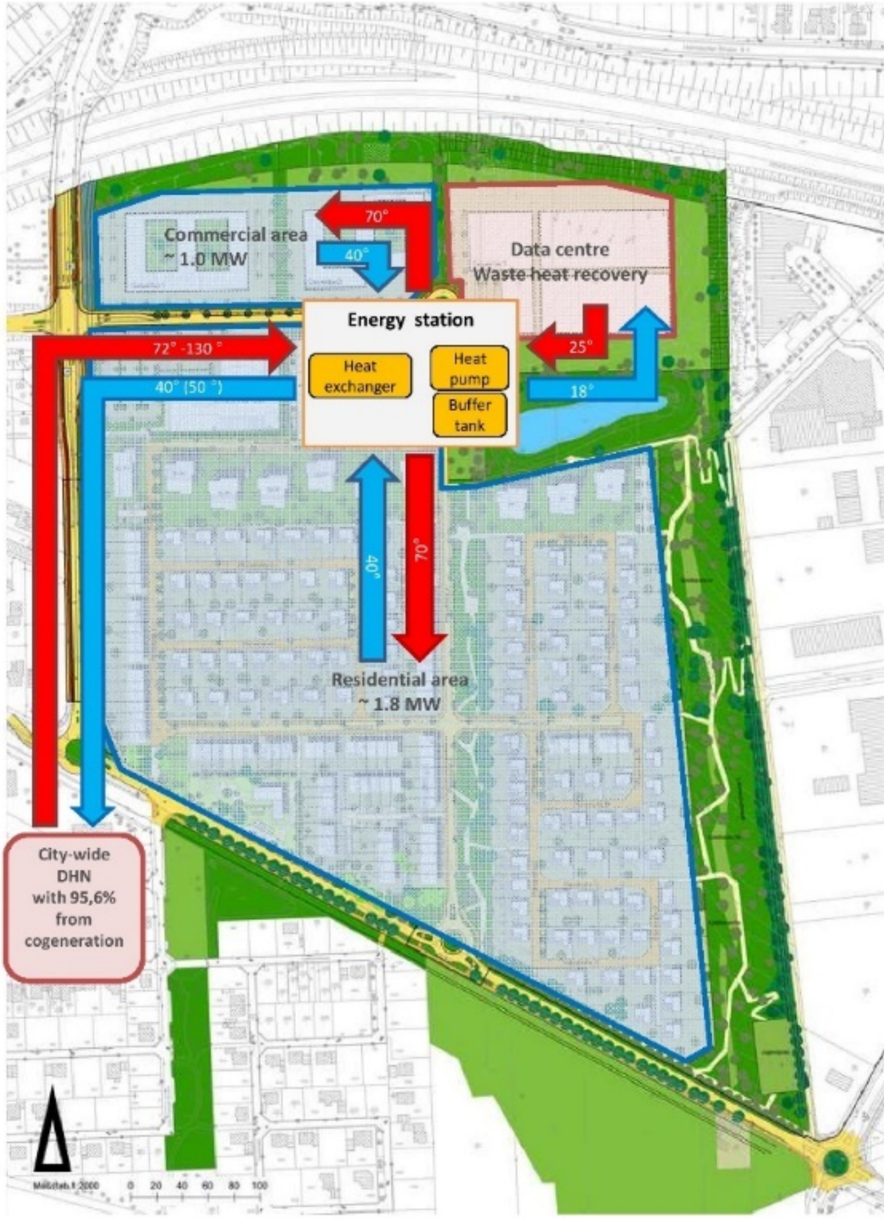


Figure 8. Plan of the newly built area.

Customers are supplied with hot water at 70°C. Keeping the temperature of the LTDHN supply as low as possible is desirable for high efficiency. However, a trade-off is necessary between the technical efficiency of the system and clients' sanitary concerns as temperatures below 65°C could favour the development of *Legionella* bacteria. The peak load of the residential area is estimated at 1.8 MW and the potential load of the commercial area is estimated at 1.0 MW.

Heat recovered from the data centre covers the base heat load of the residential area. The peak load is provided through a connection to the existing high-temperature DHN, a section of which runs near the new development (see Figure 8, above).

3.1.3 Performance

By the end of the project (September 2022), the monitored data for the performance of the demonstrator will be presented here.

3.1.4 Lessons learned

- Long distances between the heat source and heat consumer decrease performance and increase costs.
- A LTDHN is required for low-temperature sources
- Replicability is limited – each demonstration site is a different size, distance from the network and offers different temperatures.
- The reuse of waste heat is not a priority for data centre operators as it is not within the scope of their business: the data centre’s key priority is the security of its operations and establishing a dialogue can take time.
- Waste heat recovery is new to DH operators, data centres and system installers.
- The heat pump market has limited choices of natural refrigerants with low global warming potential.
- The payback period is longer than usual at (due to the system being a novelty)- this is a result of carbon being priced too low
- For the Braunschweig demonstrator, it was important to mitigate the risk of not obtaining waste heat at all times with a pipeline to the high-temperature DHN.
- Data centres scale up activity gradually, so the full volume of waste heat is not available early in the data centre’s operation.
- Only part of the waste heat volumes foreseen from the datacenter are recovered with the LTDHN
- The building owner may install solutions for hot water (hot water tanks rather than flow-through systems) that make heat recovery in summer difficult because overly warm water is returned to the heat pump. This must be discussed and agreed upon early on in the contract writing stage.

3.2 Hospital heat recovery

3.2.1 Introduction

ASIME is part of Grupo Empresarial Electromédico (GEE), a business group founded in 1982 encompassing more than 900 professionals around the world. ASIME is present in more than 160 hospitals in Spain and more than 190 hospitals internationally. It represents large, medium and small hospitals. The company is an ESCO. The demonstrator in ReUseHEat is the hospital Severo Ochoa. Its location in Madrid is shown in Figure 9 and Figure 10.

Figure 9. The hospital Severo Ochoa in Madrid.

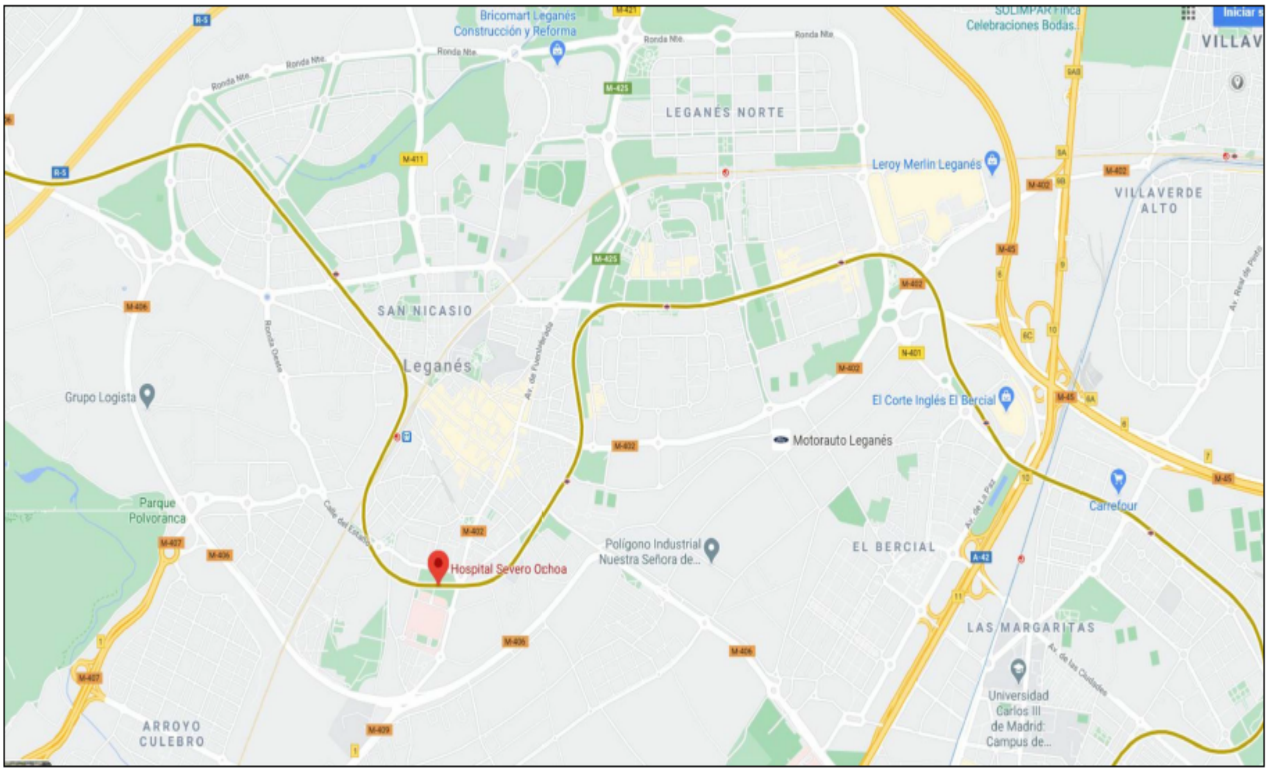


Figure 10. The location of the demonstration site in Madrid.

To optimise efficiency and energy savings, parameters such as temperatures in the chillers' cooling circuit and local DHC, instantaneous boiler efficiencies and energy prices must be considered. This is one of the main innovations in the project. The system mainly works in Summer when the cooling demand is high, and the heating demand is low but is also effective in heating seasons because of the simultaneous heating–cooling demand as described above. Most of the savings will be obtained in Summer when the efficiency of the heating production system is very low as the boilers are working with an inadequate, low load. In Autumn,Winter and Spring, the booster heat pump can be used with a backup of natural gas for efficient operation with the advanced control system.

The benefit of the installation is that waste heat recovery can replace the use of gas-fired boilers. Through the booster heat pump, water from the chillers' cooling circuit is cooled, minimising the usage of the cooling towers and, if the heating demand is insufficient to absorb this heat production, it will be sent to the DHN tanks (60–65 °C), reducing the need to produce hot water with the natural gas boilers. The new, advanced control system will improve the operation of the heating production system.

3.2.2 Concept

ASIME demonstrates an advanced solution based on heat recovery from a cooling process. Cooling is vital for hospitals in surgery rooms, so it is necessary year-round. Hence, electric chillers are typically used for cooling purposes that dissipate excess heat to an air, ground or water source. Usually, this heat is "wasted" and released to the environment or, if recovered, it normally only meets the temperature demands for hot water. However, with a booster heat pump, this heat can be recovered and upgraded to a suitable temperature level for heating in a building or DHN, ensuring significant primary energy savings and CO_2 emissions reduction.

The demonstrator recovers low-temperature heat from the cooling circuit of the water–water electric chillers. Before installation, the heat was dissipated through cooling towers. The booster heat pump captures the heat from the outlet water of the chiller cooling circuit and upgrades it to supply to the DHN. The booster heat pump cools the water from the chillers' cooling circuit, minimising the usage of the cooling towers. The conceptual design is illustrated in Figure 11. A comparison is shown between the ReUseHeat solution and the baseline before the demonstrator was implemented.

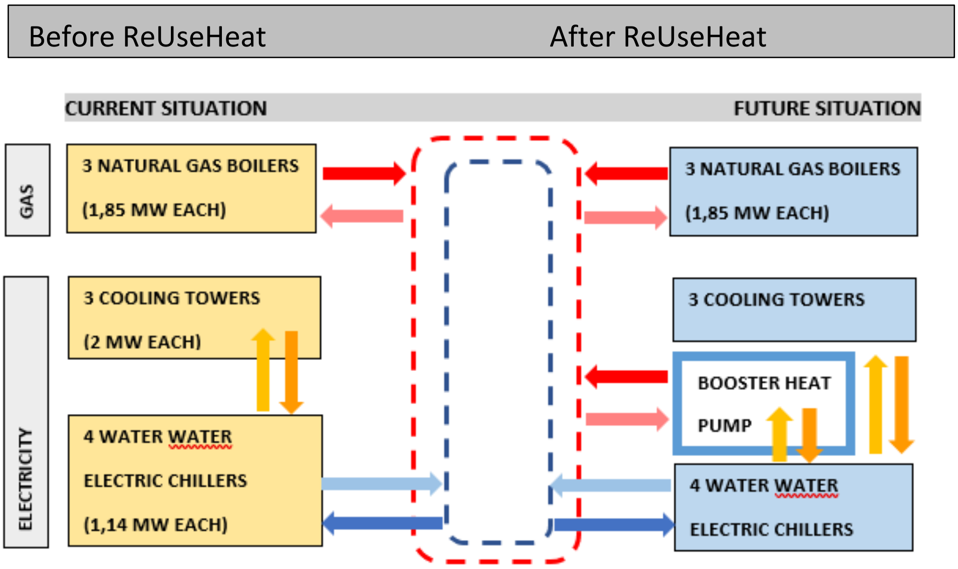


Figure 11. Booster heat pump for hospital waste heat recovery concept.

The central hospital heating and cooling production systems are composed of the components shown in Table 7:

Table 7. The hospital heating and cooling system components.

Unit	Technical solution	Capacity
Heating plants	3 natural gas boilers*	3 x 1.85 MW
Cooling plants	4 water-water electric chillers	4 x 1.14 MW
Cooling towers	3 towers	3 x 2 MW

*Gas boilers substituted for diesel boilers in April 2019.

The demonstrator recovers low-temperature heat from the condensation circuit of the water-water electric chillers. Previously, this heat was dissipated through the cooling towers. The heat is upgraded to 50–55 °C and injected into the local DHN to partially satisfy its thermal energy needs. The booster heat pump captures the heat from the outlet water of the chillers' condensing circuit (25–35 °C), which is used to generate hot water at a satisfactory temperature and varies depending on the control system but can be up to 50–55 °C, which can be injected into the local DHN. Through the booster heat pump, water from the chillers' condensing circuit is cooled, minimising the use of the cooling towers and saving energy and water.

The hospital is a public hospital in three buildings that offers medical services to Madrid citizens. The hospital has a local network to supply all the buildings with heating and cooling. The demonstrator's distribution system is formed by primary and secondary pipelines that distribute hot and cold water through the building complex. The first technical scheme drafted is illustrated in Figure 12.

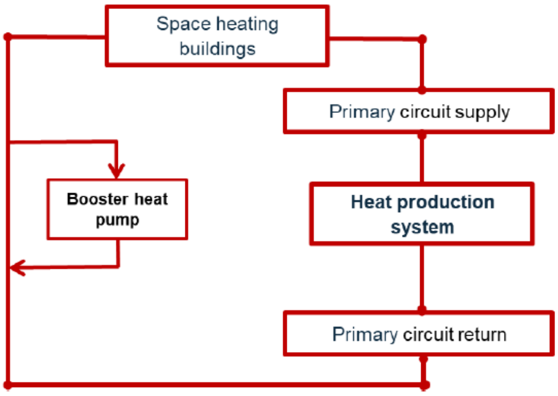


Figure 12. The concept of the hospital demonstrator's distribution system.

Few examples of waste heat–heat pump systems for tertiary buildings are known in the EU. The existing ones reuse heat at low or medium temperatures and are coupled to the building heating production system with traditional gas boilers or other waste heat sources, such as ground sources. ReUseHeat learned that waste heat recovery systems are normally designed for preheating and their temperatures are too low to meet supply requirements. Integration with DHN is required as heating and cooling needs are not always simultaneous and advanced control systems are necessary for optimal efficiency and to make investments reliable.

3.2.3 Performance

By the end of the project (September 2022), the monitored data for the performance of the demonstrator will be presented here.

3.2.4 Lessons learned

- Large tertiary buildings may have large facility schemes; each project will have a specific and non-generic solution.
- Special attention must be given to agreements with public entities. The terms and deadlines are extended, and they take extra time to conclude.
- Sensors and control elements are necessary to obtain useful data (deviations can be recognised by the hospital's BEMS more quickly).
- Recovering heat from cooling towers has great potential.
- Seasonal heat recovery from cooling towers is insufficient; it should be year-round.
- In-depth facility knowledge is important for successful heat recovery success.
- Possible improvements must be evaluated for successful heat recovery.
- The pandemic made work in the hospital sector extremely challenging.
- Extreme weather made work in Madrid extremely challenging.

3.3 Metro heat recovery

3.3.1 Introduction

The metro demonstrator was not realised in the ReUseHeat project because key stakeholders withdrew from the project with less than one year of project time remaining. The demonstrator first encountered difficulty when the initial partner had to exit the project. A replacement site was found within one month of the original partner leaving the group.

Work progressed well at the new site, which was advantageous because the heat source was located close to the end user. A room at the end of the metro platform was available for the heat pump installation. Almost one year after the replacement site was selected and detailed planning was performed the metro operator announced that they were rebuilding the planned room for the heat recovery. The room would be transformed into a new exit stairway from the station. The reconstruction would delay the ReUseHeat demonstrator by 24 months. This was not seen as an alternative and a third site was identified.

This site was challenging as it necessitated installation between tracks and a transmission line between the heat source (the tunnel) and the end use (building of the metro operator). The transmission line was costly and switching the installation from a room adjacent to the platform of a station led to a situation where the safety regulations of the metro had to be respected. Regulations limited the access to the site complicating both construction and future maintenance.

In terms of timing, the second replacement site was identified just before the Pandemic spread across Europe, which made planning the implementation difficult (online meetings). Due to the impossibility of physical site visits some elements were not included in the offer to the subcontractor and the offer had to be withdrawn and updated which took time. Even so planning progressed.

On the contractual side, the ReUseHeat partner necessitated arrangements with the metro operator and the local district energy company that would take over the installation once it had been validated to operate it continuously. The contractual discussions were further complicated by people leaving both the metro organisation and the energy company and negotiations had to be restarted with new people from scratch. Another complication of the Pandemic was that material costs increased as did the predicted transportation times of equipment. Finally, the key stakeholders withdrew from the implementation of the waste heat recovery when 9 months remained of the project. At that point in time no replacement site was deemed possible, and it was decided to not pursue the implementation of the site.

3.3.2 Concept

The concepts designed for the first site and the first replacement site were similar, while the second replacement site was different, particularly in the distance between the heat source and heat use. Below, the concepts for both intended installations are presented. At Ernst Reuther Platz Station, the first replacement site, there were several side rooms for service and staff (Figure 13).

Figure 13. Side room of Ernst Reuther Platz Station, offering easy access (first replacement site)

An ideal location for the heat pump and evaporator was found in one of these side rooms. Two openings would have been needed to supply the air of the tunnel into the heat pump room. Because the heat pump could have been placed next to the evaporator using the heated source air, a direct expansion system was chosen. Complete and detailed planning and pre-purchasing took place.

The station system at Ernst Reuter Platz and the system location are shown in Figure 14 and Figure 15.

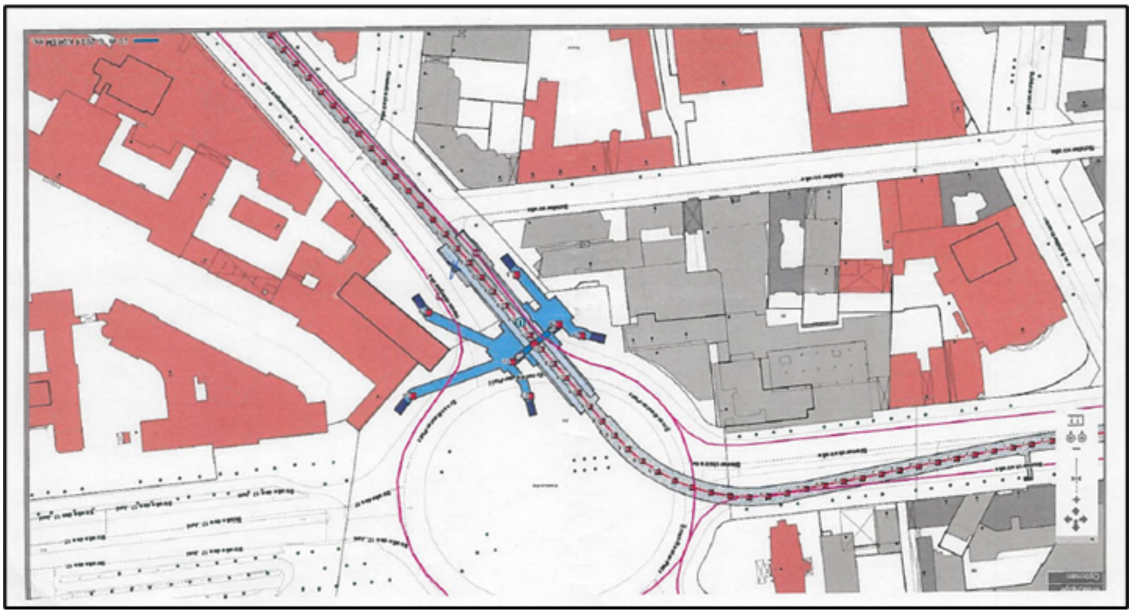


Figure 14. Metro demonstrator system at Ernst Reuter Platz Station in Berlin.

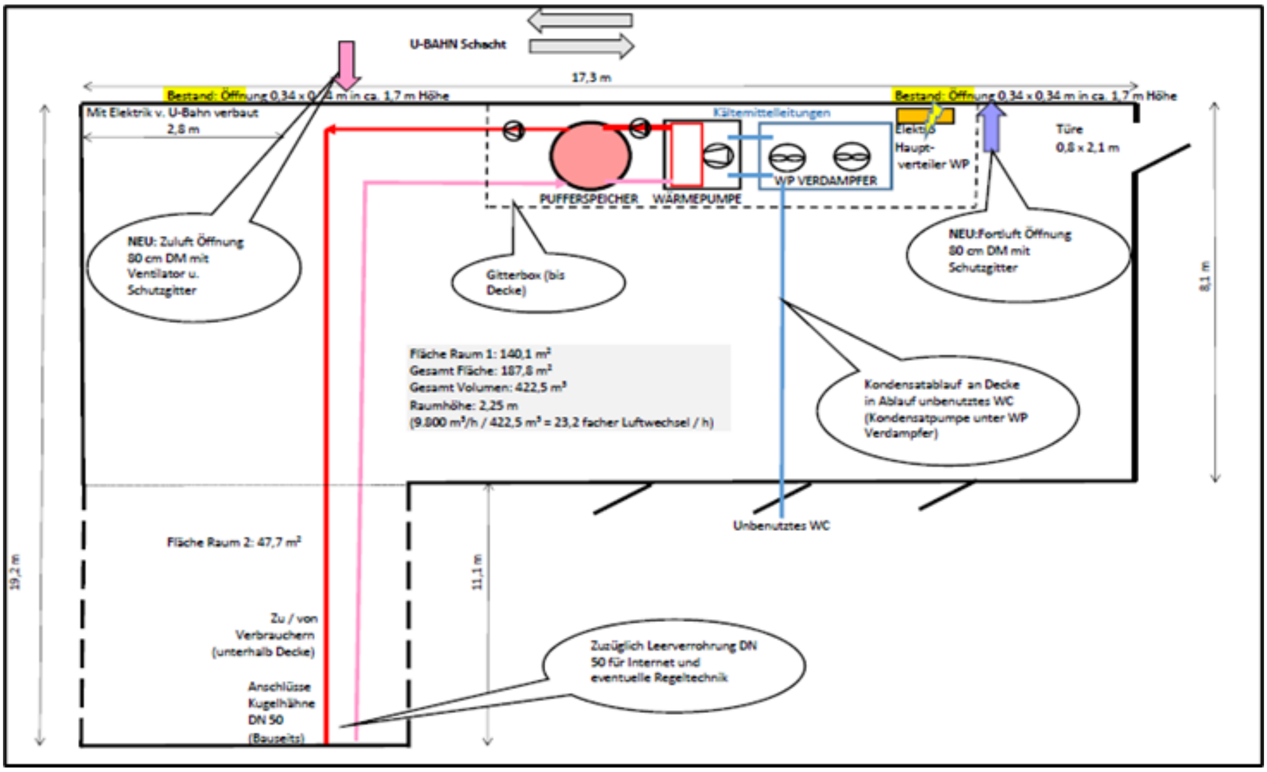


Figure 15. System location illustration of Ernst Reuther Platz Station.

The illustration shows the easy access from the station or passenger room to the side room where the heat pump would have been installed. This room is also directly adjacent to the tunnel with the rails. Here, a direct expansion heat pump and the evaporator, which is the fan coil gathering the ambient heat from the air, could have been installed side-by-side. This would have avoided any losses between heat capture and heat pump (direct expansion system). The heating pipes (in red) would have connected the buffer tank to the building. To guarantee a constant heat exchange and, so, a constant heat source, a fan would have been installed in one of the two existing openings or windows to the rail tunnel. This system would have been roughly half as costly as the one later planned at Frankfurter Allee.

For Frankfurter Allée, the second site in Berlin, the recovered heat could have been used by the metro operator itself in a nearby building in winter. The waste heat would have replaced the direct electrical heating. The heat pump was ultimately sized for heat delivery into the neighbouring building, the metro operator's Gleichrichtertwerk (rectifier plant), through a local grid. In addition, the local district energy company foresaw to operate the system post ReUseHeat. The company intended to connect the heat pump with the larger city DHN.

Figure 16 shows, on the left, the twin air cooler units and their respective ventilators that would have been the heat source. They would have been placed between the two rails. The insulated collection pipes to the storage/source buffer tank would bring the ambient energy to the heat pump. According to assumptions about the source system temperature, they would never be near freezing, so no brine would have been provided. The planned heat pump was a water-to-water type. On the hot side, a warm buffer tank would have been provided and connected to the local heating grid for the building. Heat transfer would have been accomplished with radiators. Optional pipe connections could have been connected to another, larger, neighbouring building. In this case, larger air coolers and a larger heat pump would have needed to be installed.

Working on the concept it was identified that metal dust was heavy in the air from the metro tunnel. It would have been managed by a closed system under a protective cover: ensuring heat pump performance not being impacted. The concept of the demonstration site at Frankfurter Allée is shown in Figure 17.

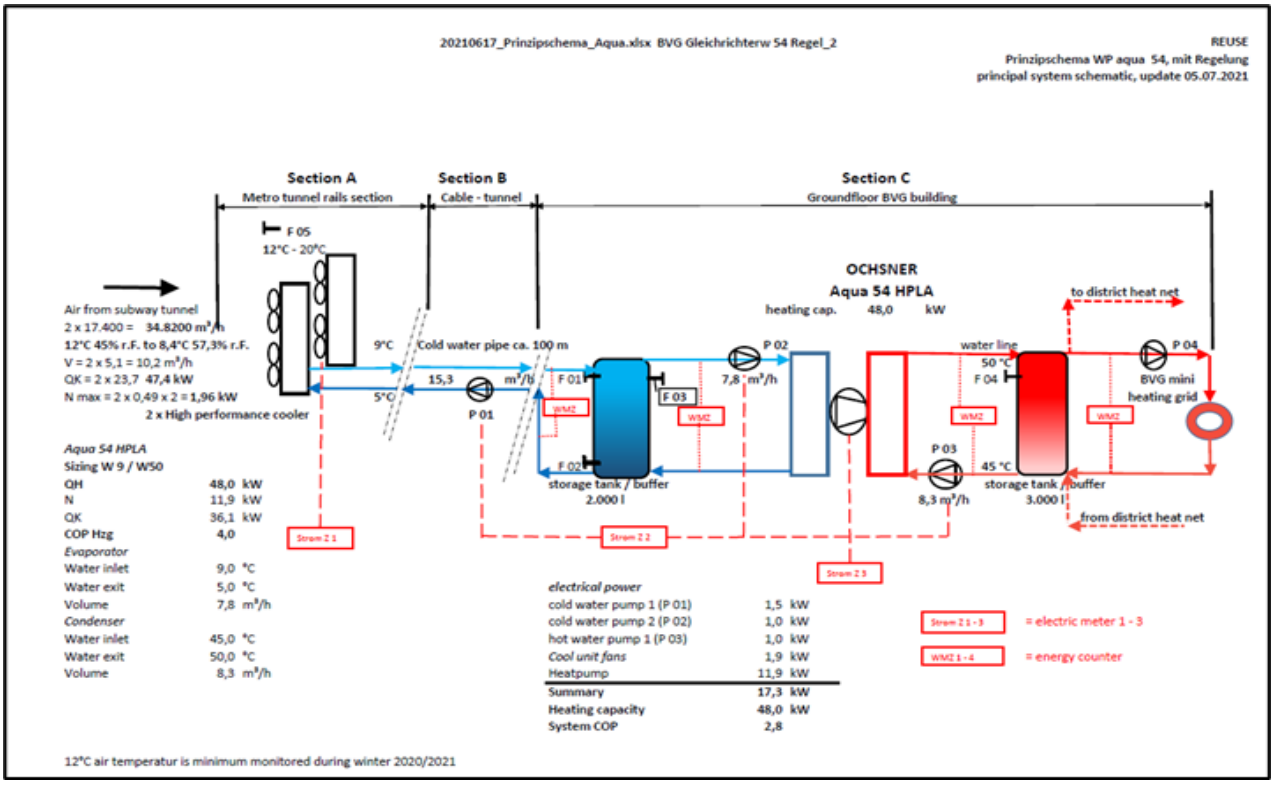


Figure 16. System illustration of the heat recovery system planned for Frankfurter Allée in Berlin.

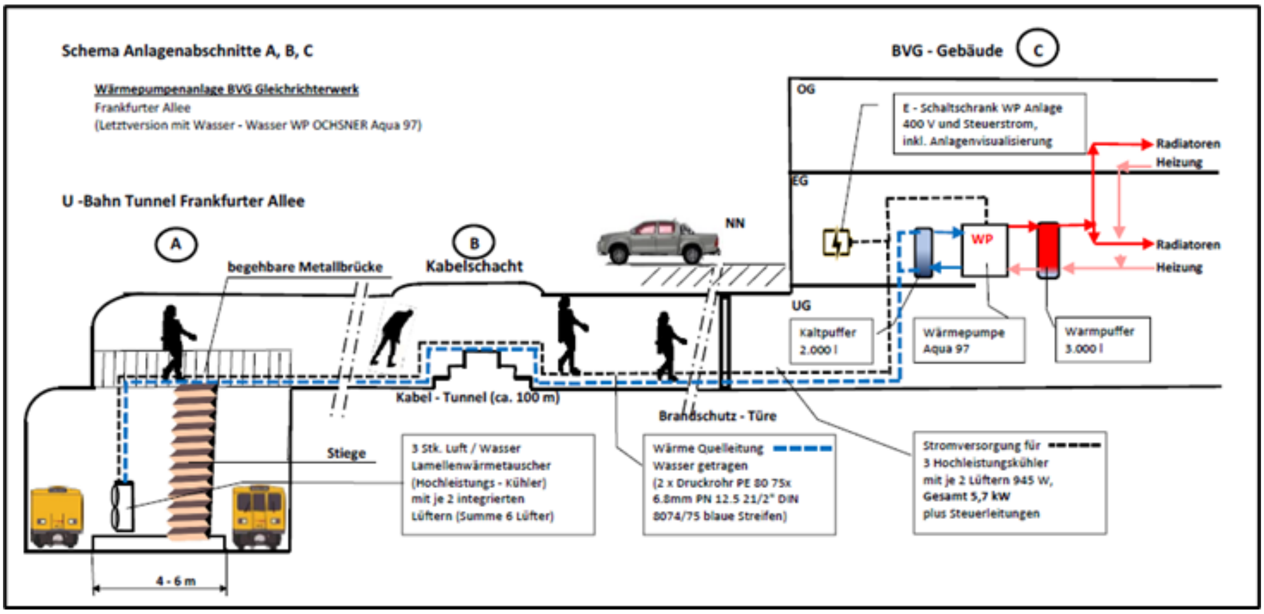


Figure 17. Concept illustration for the Frankfurter Allée site in Berlin.

On one hand, the concept shows a more demanding and costly system due to the large distance between the metro tracks and the heat pump in the building. On the other hand, it illustrates that even under unfavourable conditions, a heat recovery system can be installed.

How the recovered heat would go from the metro tracks to the buffer tank is illustrated. Heat would have been recovered between the tracks and moved into a pipeline of over 110 meters in length. The pipeline would have gone over a metal bridge (A), through an electric cable shaft (B) and through a security door into the metro building that was intended to be heated (C).

3.3.3 Performance

The first installation, in Bucharest, would have been the largest. The first site in Berlin (Ernst Reuter Platz) was smaller but with similar technical solution as the one foreseen in Bucharest. The second site in Berlin (Frankfurter Allée) was further downsized and had a different concept than the original idea (with heat recovery between tracks and a transmission pipe for transporting the heat from the source to the usage).

The impact of the demonstrator has been reduced substantially since the proposal stage (Table 8).

The metro installations' scalability was foreseen to have the highest potential amongst the ReUseHeat demonstrators as this type of installation could be standardised and implemented in any metro tunnel without necessitating the major reconstruction of the tunnel. This contrasts with the heat recovery investigation of the CELCIUS project in Islington Station in the London Underground, where ample reconstruction was needed because the heat was recovered from the ventilation shaft.

Table 8. Development of the replacement metro demonstrators.

Impact	Bucharest	Ernst Reuter Platz	Frankfurter Allée
Supply of waste heat (MWh/yr)	1,100	350	161
Waste heat recoverd (MWh/yr)	850	268	115
Primary energy savings (MWh/yr)	644	235	187
CO_2 emissions savings (tonnes/yr)	116	48	60

The temperature in the tunnel was monitored; by the end of the project (September 2022), the monitored data from the tunnel will be presented here. The data will indicate the volumes of waste heat that could be recovered from the tunnel.

3.3.4 Lessons learned

- The distance between the heat source and the heat user is an important barrier to the economic viability of waste heat recovery from the metro
- The permits needed for waste heat recovery can be time-consuming to acquire when waste heat recovery experience is limited.
- Waste heat recovery is not the top priority of metro organisations nor of large energy companies, which makes the decision-making process difficult and slow
- Defining the limits of the waste heat recovery system takes time and knowledge and, to be efficient, several stakeholders need to work simultaneously to understand the limitations.
- Recovering heat from the tunnel can be difficult if it needs to account for the safety regulations of the metro operation
- Recovering heat from a metro tunnel necessitates the management of metal dust in the air.
- The ReUseHeat solution has the advantage of being highly modular and scalable. In a system where one ReUseHeat recovery unit is installed, it should be easy to scale up the number of heat recovery units.
- The surrounding soil conditions of a metro system will affect how warm the system is during Winter and Summer and its need for heating and cooling.
- The best stage to consider metro heat recovery is most likely when designing new tracks or stations so it can be a built-in

3.4 Awareness building demonstrator (dashboard)

3.4.1 Introduction

City residents have limited awareness of the possibility of recovering waste heat from everyday activities like those featured in the ReUseHeat project, or renewable energy more in general. Particularly, in France, where only about 6% of the total heat demand is provided by DHCN networks, awareness on DHCN themselves is rather absent. As most DHCN projects in France, in order to be viable, a certain minimal heat demand density has to be ensured. Thus, projects are associated to a mix of commercial/tertiary and multi-family real estate projects, instead of pure low-density residential area with little or no tertiary services. In such context, DHCN suppliers (being public or private), have a direct contractual relation with its customers sourcing energy from the primary network so interfacing building owner/operator, rather than tenants, which are interfaced on the secondary network side via the building owner/operator. DHCN projects based on single family housing are rare if not absent in the French context. End-users are thus barely targeted by communication and commercialisation actions concerning DHCN undertaking, and new means to reach them have to be found.

The dashboard demonstrator is primarily intended to show, in real time, the use of different energy fluxes supplying DHCN networks and make it accessible and more importantly, acknowledgeable, by any citizen. Once there is knowledge and a capability among stakeholders to “think outside of the box”, and end-user acceptance is secured, there can be a wider adoption for urban waste heat recovery solutions. Currently, solutions are not widely acknowledged and yet big obstacles in terms of a-priori concerns towards general technical aspects (technological viability and costs) or environmental impacts (sound, air, water pollution) remain, as stakeholders and end-users have limited knowledge about these aspects.

The need for this kind of “awareness demonstrator” was identified jointly by the energy company EDF and the city of Nice. Nice seeks to be “the green city of the Mediterranean region” and a forerunner in the French and international context for new approaches on local smart and low-carbon energy systems and end-user engagement.

3.4.2 Concept

The dashboard can be placed on any LTDHCN (based on waste heat or a renewable source) to showcase its overall environmental performance and working principles. The dashboard was built with a design thinking approach shown in Figure 18. The process was initiated to achieve a minimal viable product (MVP), to be used to validate end-user interest under real conditions (Technical Readiness Level, TRL, 7) was targeted. From the end-user feedback, the MVP was further developed and enhanced with the received feedback towards a qualified product (TRL8).

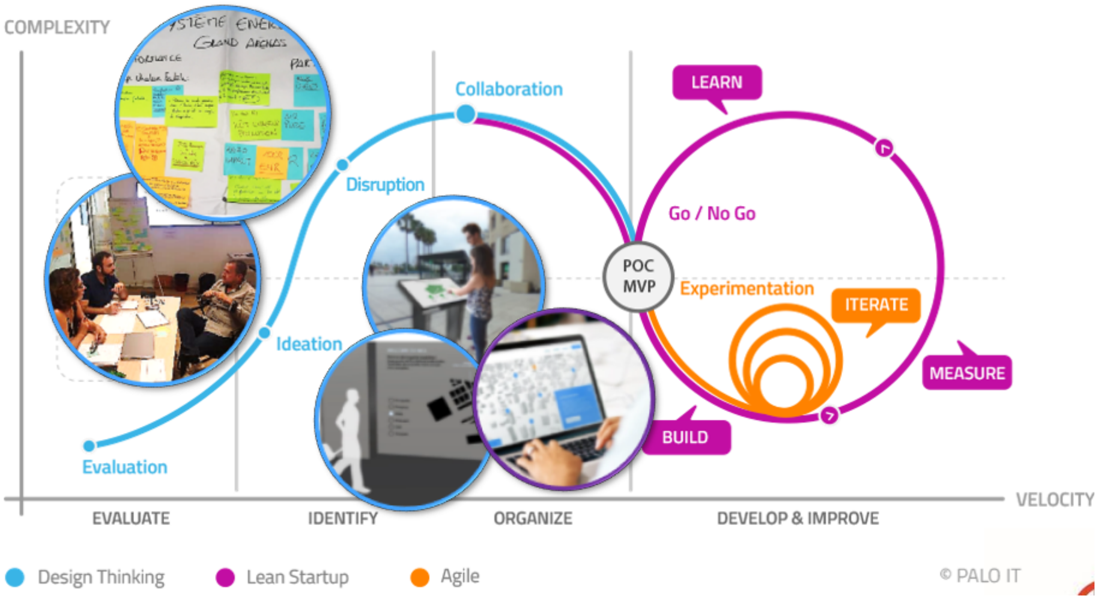


Figure 18. Schematisation of the followed methodology to achieve the MVP via a design thinking approach, further improved via an agile approach and under verification via a Lean Startup approach (source: EDF).

The very first step undertaken, was to identify potential existing literature and similar products to be taken as base for the ideation approach. Nevertheless, despite existing “public interfaces” which could be related to the public realm, it was identified that none was adapted for the purpose of the Dashboard. Based on a French user-centred questionnaire, towards energy and environment related matters, a clear need to develop more transparency on local energy systems could be validated.

This knowledge was condensed and put into use in a first participative workshop (WS) based on a design thinking approach (Figure 19). The WS was organised by EDF with all main stakeholders (local authority, DHCN operator and internal and external partners). The objective of the WS was to retrieve all possible information (divergence and exploration) coming from the different stakeholders concerned by a Dashboard and jointly achieve a first rough Business Model Canvas (BMC). The WS was divided in three main phases: brainstorming, inspiration and co-construction. Brainstorming was needed to retrieve unbiased expectations and ideas from all participants. Inspiration was a first restitution of the work undertaken, exploring 3 different types of Dashbaord concepts. These were (i) a web based solution to be delivered to end-users via different channels, (ii) a touch-screen made available in public spaces e.g. a “self-explaining” platform that could be explored by any passer-by and (iii) last but not least, use the nearby airport as main mean to raise awareness in a very widespread manner, targeting not only local citizens but also the great number of private or business travellers passing by the second largest airport in France. Co-construction, is the phase of convergence of the workshop, towards first sketches and ideas on the possible BMC.

Figure 19. Schematisation of Design Thinking WS organised by EDF and its main phasing. Source: EDF

The MVP (Figure 20) was identified and it was the web-based solution. It enabled to answer the needs and expectations retrieved from the WS and made the question of the channel to be used (digital interfaces being private – laptops, mobile phones – or public ones – touch-screen or other advertisement/interactive screen in the public domain) a secondary aspect.

Therefore, development to define the Wireframes, also known as a page schematic or screen blueprint was undertaken. The visual guide or static model representing the skeletal framework of the targeted digital interface, by representing the precise organization of elements on the screen in terms of figures, text and contents (without going too far in the definition of texts’ or images’ content or form) was built.

This stage enabled to launch needed IT developments in interface with the DHCN operator from where the data are retrieved. The architecture imposed by the DHCN operator, in order to ensure the facility realm (DHCN’s SCADA) would be secured from any interference and intrusion, was to interface the Dashboard server, with the operator’s regional control system, choosing to “push” data towards the server. From the server set up by EDF, the user realm could be developed, based on the provided Wireframe (Figure 21).

Figure 20. The first MVP retained wireframe model (left picture) and its first visual prototype (right picture). Source: EDF.

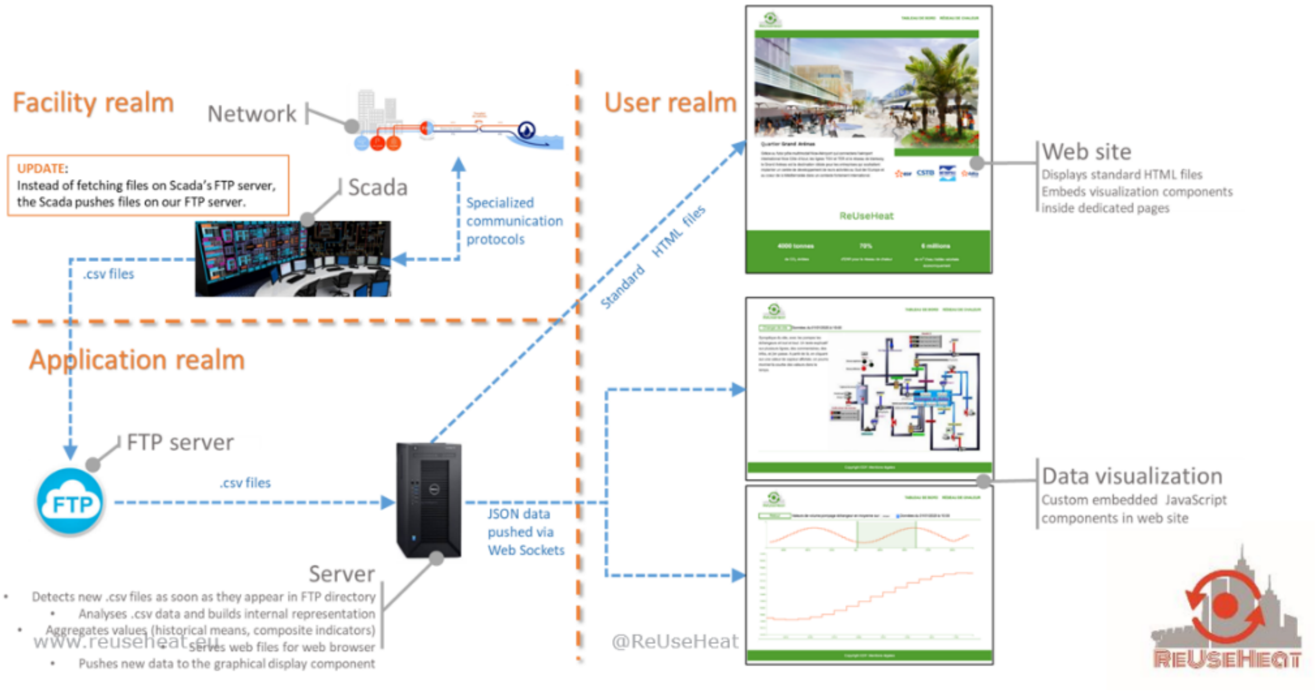


Figure 21. Scheme of the implemented IT structure for the programming of the dashboard. Source: EDF.

Once the development of the MVP was complete, it has undergone three main interactions through an Agile process (steered by the dedicated unit in EDF's Mediterranean Direction, called MedInLab). These interactions have enabled to obtain rapid end-user feedback and to implement meaningful feedbacks. This process gave input and support to adjust the Wireframe and its content. Feedback was the following: simplification, schematisation and contextualisation (Figure 22).

Simplification, reflects a need to break down all technical wording and concepts towards common language and make information tangible for any kind of user. For example, "waste heat recovery" had to be simplified towards "energy recycling", a word that made much more sense to all users providing feedback. This enabled to catch their interest and introduce the matter in a proper manner. Text needed to be largened to use longer periphrases and explanations as concepts could not be reduced to the technical wording used by "insiders" of the DHCN realm.

Schematisation was a consequence of simplification, as the whole system had to be explained based on its components. It was decided to enable, in the wireframe. to move via schemes among the main DHCN components. These were source, distribution network, substation and additional concepts, as needed by the user or guided by his/her interest to know more about the technology. These sections were enriched with text, accompanied by video-animation, chosen by questioned users as their preferred mean of communication.

Contextualisation refers to the need of users to understand what data relate to. The real-time data represented in curves or graphs at different scales of resolutions need to add value. Therefore, it was decided to overlay real time data on graphical representations of the source and substations, and from there, give the user the possibility to explore the displayed data more in detail.

Simplify – avoid all technical wording and explain instead !

Simplify wording

ENERGY RECYCLING, HOW DOES IT WORK?

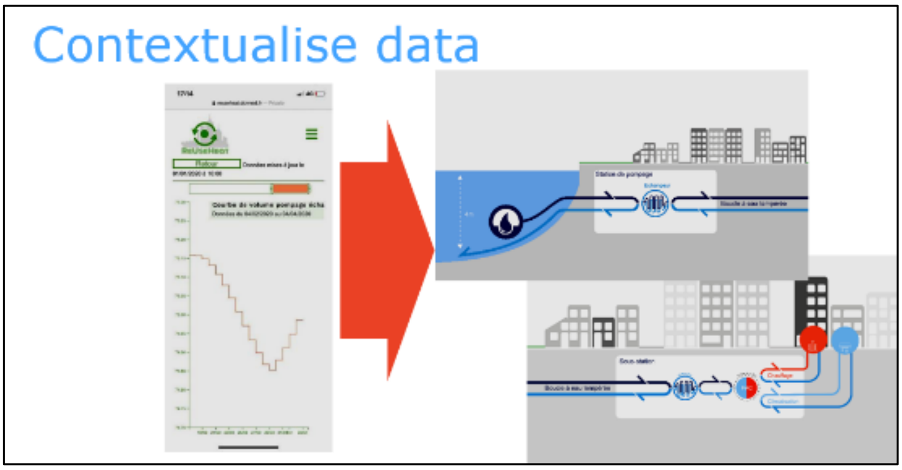
New technologies enable the use of warm heat sources to heat or cool buildings. Here we use the energy of the sea water, pumped at a depth of five meters. This energy will be carried away by a fresh water network running through the city. This network allows the recovery of the dissipated thermic energy produced by the heat pumps, which would normally be wasted in the air surrounding the building.

Schematize

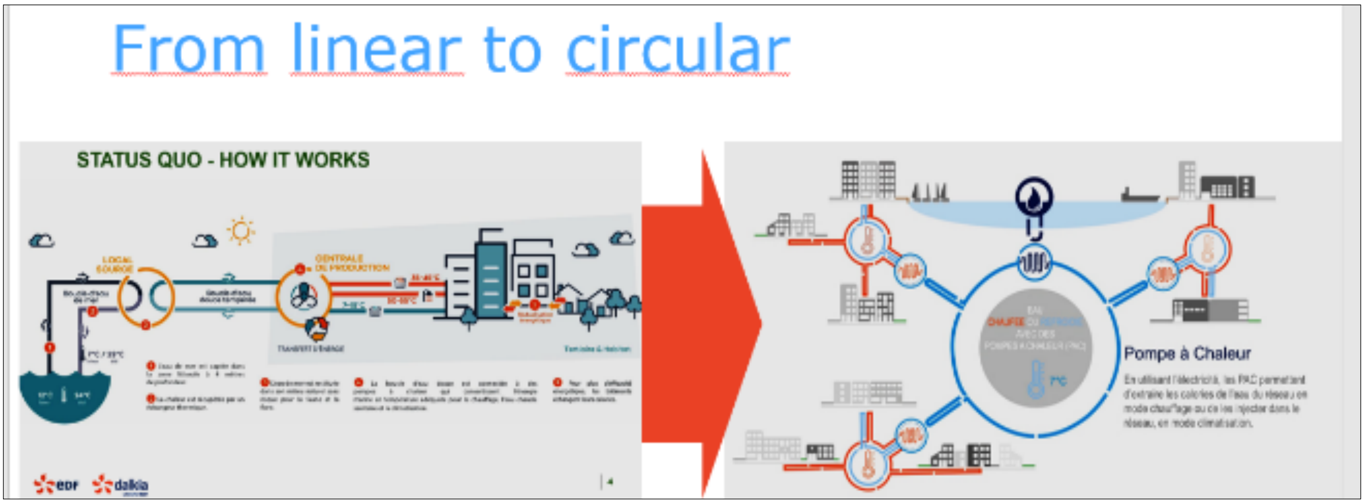
Explanatory animations

www.reuseheat.eu

@ReUseHeat



Contextualise data



From linear to circular

STATUS QUO - HOW IT WORKS

Pompe à Chaleur

En utilisant l'électricité, les PAC permettent d'extraire les calories de l'eau du réseau, en mode chauffage ou de les rejeter dans le réseau, en mode climatisation.

Figure 22. Exemplification of different lessons learned via the Agile process that had to be implemented in the dashboard. Source: EDF.

The three steps led to the final stage of development, which concerned the retrieval of large spread user feedback. It was obtained via an online questionnaire and integrated into the final and qualified product. In combination with the online questionnaire, a social-study campaign was launched, targeting to have qualitative, in-deep feedback via individual interviews with local authority members, DHCN operators and users. Two persons for these three categories were targeted totalling six in-depth interviews.

3.4.3 Performance

In terms of technical performance of the Dashboard towards hosting larger, and longer term time series of data or larger number of users, these were tested during the first implementation phases via mock up data and has proven to ensure stable operation if scaled or replicated. **At the end of the project, (September 2022) data on the performance of the dashboard will be provided here.**

3.4.4 Lessons learned

- To create awareness information must be focused on making the technology understandable and to explain its advantages in the simplest way possible, in terms of language and form of used media
- Data are not valuable if not contextualized via graphics or other contextual elements that users can relate to
- The Design Thinking approach for building a suitable MVP, based on a Wireframe model, tested via an Agile method end-user' feedback, and finally build the products and undergo the measuring and qualification of the products under real conditions, has been validated as an efficient methodology
- The development of a dashboard system, necessitates a review of data management and availability of, for example the DHCN
- Through the exchanges in ReUseHeat, a cross fertilization has taken place, where faults in data were detected and removed

3.5 Scalability and Replicability

Scalability can be defined as the ability of a system, network or process to change in scale to meet growing volumes of demand. Modularity refers to whether a solution can be divided into interdependent components or not. High modularity offers a high potential for scalability. Modularity is accounted for in an analysis of scalability. By contrast, **replicability** denotes whether a system, network or process can be duplicated at another location or time in a modular fashion. Several factors, listed in Table 9, have been applied to assess the scalability and replicability of the demonstration projects. The scalability and replicability of the four sites were assessed based on questions asked to the demonstrators.

Table 9. Scalability and replicability factors.

Area	Scalability factors	Replicability factors
Technical	Modularity Technology evolution Interface design Software integration Existing infrastructure External constraints	Standardisation Interoperability Interface design External constraints
Economic	Economy of scale Profitability	Business model Economy of scale Market design
Regulatory	Regulation	Regulation
Stakeholder acceptance	Acceptance	Acceptance

The cumulative results are presented in Figure 23. The scalability ratio (index) and the replicability ratio (index) are above 50% for all demonstrators. For the hospital both indices are highest.

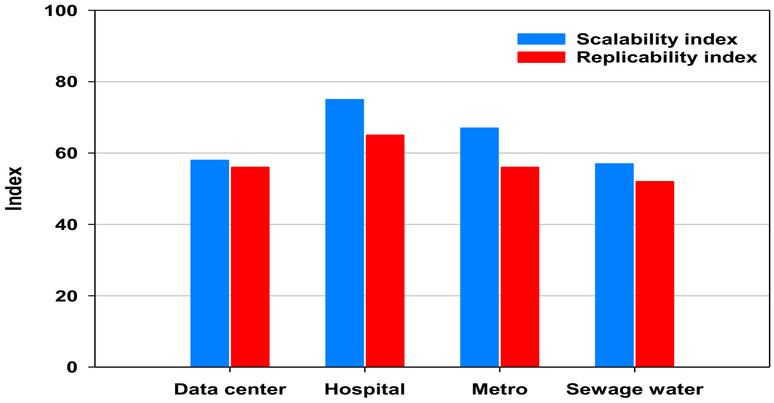


Figure 23. Aggregated scalability and replicability indexes by heat source.

From the analyses it was identified that economy of scale was a factor with one of the highest scores for scalability for all four demosites. For three of them the profitability was also an important factor. For one demonstrator, regulatory issues obtained a high score for scalability. Software integration, interface design and technology evolution were factors with low scores for all four demosites. Scalability indices are summarized in figure 24.

From the analyses it was identified that economy of scale was a factor with medium score for replicability for all four demosites. Regulatory issues was a factor that all four demonstrators addressed but at different scores where one score it high for replication, two gave it medium score and one low score. The business model and acceptance was highly scored by one demonstrator. Again, interface design had a low score of all demonstrators as did interoperability. Replication indices are summarized in figure 25.

Considering the value chain of the urban waste heat recovery investment (Chapter 2) most important stakeholder groups for urban waste heat recovery investments were identified: (i) DH companies, (ii) owners of waste heat (iii) end users of urban waste heat recovery solutions (iv) policymakers and (v) investors. A deeper analysis per demonstrator site than shown in the aggregated scalability and replicability measures generated learnings for each of these stakeholder groups (for full information please visit D2.9, Scalability, Replicability and Modularity).

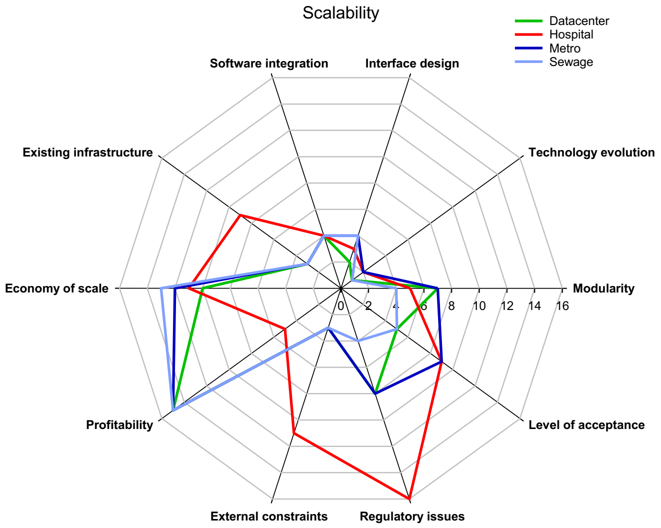


Figure 24 Computed Scalability Indices

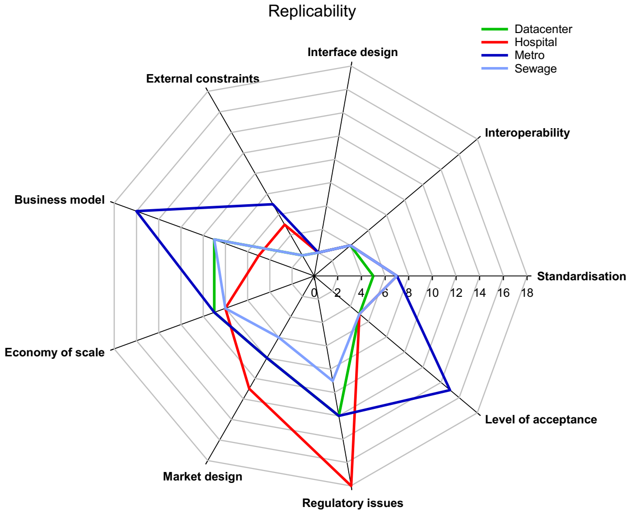


Figure 25 Computed Replicability Indices

Learnings for district heating companies

1. The distance between the heat source and DHN cannot be too great.
2. System innovations are possible and not limited by national regulations or standards. The local safety regulations in metro tunnels are, however, challenging.
3. The acceptance of the waste heat owners is crucial for success.
4. The acceptance of end users and policymakers will drive long-term demand for the solution.
5. Adjustments must be made for each site; there are no universal system solutions.
6. Depending on the ownership constellation in place for the heat recovery, the preconditions will differ significantly.

Learnings for waste heat owners

1. Low-temperature waste heat recovery is a new concept for both developers and waste heat owners and there are no standardised solutions.
2. Urban waste heat recovery solutions can be seen as cooling services.
3. Utilising waste heat makes the energy fluxes in the district greener.

Learnings for end users

1. Urban waste heat solutions are feasible. Heat generated by the city can heat building spaces.
2. Urban waste heat recovery can be demanded from the DH company. The customer can make it happen.

Learnings for policymakers

1. Encouraging or neutral regulations on waste heat recovery benefit urban waste heat recovery. The lack of subsidies for the acquisition of equipment and high operational costs are barriers for the development of urban waste heat recovery.
2. Rather than standardising technology, waste heat recovery should be supported. Information about waste heat compared to other renewable energy sources is needed.
3. The cost of carbon nowadays is too low, making urban waste heat recovery costly and limiting its implementation when competing with incentivised renewable energy investments.
4. In the context of municipal and public services, urban waste heat recovery can be developed further to include metros, hospitals, schools, social housing and city halls, for example.
5. National and local policy making must be differentiated. At the national level, it is important to offer incentives. At the local level is important to signal that waste heat is a valuable resource, for example, by requesting an assessment of waste heat recovery feasibility in all new construction involving public buildings.

Learnings for investors

1. Urban waste heat recovery investments can be bankable.
2. Urban waste heat recovery investments are green energy investments.

3.6 Learnings from replication sites

To foster replication of urban waste heat recovery work was undertaken with five external replication sites. They represent different, low-temperature heat sources:

- Ground water heat in London
- Datacenter heat recovery in Vilnius
- Absorption chiller and the intercooler of the cogeneration plant heat recovery in Genova
- Metro tunnel and station heat in Belgrade
- Heat from a supermarket in Vilnius

For each site, the source of urban excess heat was characterized, the main features of the heat user were assessed, the technical solution was proposed with one or more scenarios depending on the specific characteristics of the project, the energy/environmental benefits were determined, and the financial profitability was assessed, also quantifying the amount of public grant needed in case the project is not returning a 10% IRR and 10 years (or shorter) payback time.

In terms of primary energy and greenhouse gas emission savings the results varied across the sites as shown in the table below. In bold are the highest and lowest numbers.

For the metro heat recovery there are two scenarios. The first is PV usage to generate the electricity operating the heat pump (Scenario Advanced) and the second is to purchase electricity off the national grid (Scenario Basic).

For the datacenter, 5 scenarios were drafted. Numbers for the most advanced solution (with storage and PV for generating own electricity for the heat pump: Scenario Advanced) and solely heat pump recovery (Scenario Basic) are shown in the table.

For the heat recovery from absorption chiller and cogeneration plant it was identified that the Levelized Cost of Heat was higher than for the current solution making the investment alternative unattractive. For the heat recovery from cogeneration plant there was a business case, it is provided in the table.

For the heat recovery from supermarket there are two scenarios. The first is PV usage to generate the electricity operating the heat pump. The second is purchased electricity from the grid. The second alternative had Levelized Cost of Heat higher than for the current solution making the investment alternative unattractive. For the first alternative the numbers are included in the table.

Table 10. Summary of feasibility study features

Heat source	Ground water heat (London)	Metro tunnel and station heat (Belgrade)	Heat from cooling of datacenter (Vilnius)	Heat from cooling towers (Genova)	Heat from supermarket (Vilnius)
Primary Energy Savings (MWh/yr)	6755	Advanced: 10280 Basic: 6388	Advanced: 6931 Basic: 7778	709	2098
Primary Energy Savings compared to baseline (%)	51.8	Advanced: 78.3 Basic: **48.6**	Advanced: **86.8** Basic: 81.2	64.6	84.5
Green House Gas emission savings (tCO2e/yr)	2113	Advanced: 2143.9 Basic: 166.8	Advanced: 579 Basic: 608.9	91.5	180.1
Green House Gas emission savings compared to baseline (%)	79.8	Advanced: **100** Basic: **7.8**	Advanced: **100** Basic: 87.7	56.4	**100**
Paybacktime (years)	16.7	Advanced: 13.6 Basic: **12.3**	Advanced: 23.5 Basic: 15	28.1	**47.2**
Paybacktime with grant (years)	9.4	Advanced: 9 Basic: 9.4	Advanced: **9.5** Basic: 9.4	**8.6**	9.4
IRR	4.3	Advanced: 5.8 Basic: **7.1**	Advanced: 1.7 Basic: 5.2	**-3**	-2.7
IRR with grant	10	Advanced: 10 Basic: 10	Advanced: 10 Basic: 10	10	10
Proportion of grant compared to necessary investment (%)	40	Advanced: 33.8 Basic: **23.6**	Advanced: 59.7 Basic: 37.3	59.4	**80**

From the table it can be concluded that all installations shown in the table result in more than 50% savings of primary energy compared to the current solution. Lowest saving is 48.6% metro heat recovery with purchased electricity and highest is 86.8% PV for electricity use in heat recovery from datacenter plus storage. In terms of Green House Emission savings, the spread is large from 7.8% in the case of electricity from the national grid for metro heat recovery to 100% for three alternatives: the advanced metro heat recovery with PV for electricity use, datacenter heat recovery with PV for electricity

use plus storage and the cost-efficient solution for supermarket heat recovery (own PV for electricity).
The payback numbers are in the range of 12.3-47.2 years where the first is the metro heat recovery with purchased electricity and the last is the supermarket heat recovery. With grants the numbers are lowered to be in the range of 8.6 (cogeneration plant heat recovery) to 9.5 (advanced datacenter heat recovery).

The IRR is in the range of -3 – 7.1% where the first is the heat from cogeneration and the second is the basic metro heat recovery. With grants the payback is forced to 10% for each alternative.

The necessary range of grants, as proportion of the investment needed, is 23.6-80% where the first is the basic metro heat recovery and the second is the supermarket heat recovery.

Based on energy use and economic indicators it is concluded that the price of electricity is very important to the cost efficiency of urban waste heat recovery. This is a result of the heat pumps necessitating electricity to be operated. In the future it would be relevant with, for example, solar driven heat pumps (for more information on such development please consult H2020 project SunHorizon). Solutions with urban waste heat and PV generated electricity have a very positive effect in terms of Green House Gas emissions and increase the control over electricity cost.

The paybacks of the urban heat recovery investments are long and necessitate grants to become bankable. This is a result of urban waste heat recovery systems being news. Being new, they are not standardized which increases investment risk and contractual complexity. Furthermore, the absence of a legal framework identifying if waste heat is to be considered as a renewable energy source or not in the EU increases risk in waste heat recovery overall.

Learnings

- All installations reduce the primary energy need by half or more
- Paybacks and IRR are too low for commercial investors, to arrive at the commercial threshold of 10 years and 10% grants as part of investment are needed to different extents
- The temperature of the heat source and its constant or variable value during the day and the year, which strongly influences the heat pump efficiency and therefore its electricity consumption and the consequent LCOH value is extremely important for cost efficiency
- The temperature required by the heat user is influencing the heat pump efficiency
- The distance between the heat source and the heat user impacts the investment needed and the amount of heat distribution losses
- The baseline heat production system and the related average heat production cost, primary energy factor and GHG emissions factor, impact the achievable energy, emissions and economic savings
- The possibility of integrating in the project a renewable power plant, in most cases a solar photovoltaic plant, to self-produce the electricity needed by the heat pump would offset the risk of volatile electricity price. This possibility could be constrained by the presence of physical or legal barriers, in terms of space availability or of net metering permissions
- The amount of work needed for the integration of the heat pump and the heat recovery system with the existing systems (mechanical, hydraulic, electric, control aspects, etc.) will vary substantially between sites often necessitate special arrangements and bypasses
- The business model is easier in case the owner of excess heat is the heat user too, since it is not needed to guarantee margins to both sides and no need for contractual arrangements to settle the value of the heat

3.7 Best practices for successful urban waste heat recovery

Early in the project, 25 cases of that had been undertaken were identified and workshops and stakeholder meetings were held at the demonstration sites with the ambition of establishing best practices in urban waste heat recovery at the beginning of the project (information found in D3.1). During the project a number of learnings have been generated (presented in conjunction to each demonstrator above and in conjunction to the scalability, replicability and modularity analyses as well as in conjunction to the replication cases). Below, this information is condensed into a list of best practices to apply to successfully foster replication and scaling up of urban waste heat recovery investments.

BEST PRACTICES

- Ensure the quality of the source (temperature, volume, access)
- Identify the distance between heat source and heat use (it cannot be too long: transfer pipes are costly)
- Investigate if it is possible to acquire funding towards the investment cost to ensure a lowered pay-back or IRR: discuss with the local authority about the advantages of the local heat supply and ensure similar subsidies for low temperature waste heat recovery as for other investments in renewable energy
- Recognize that the waste heat provider has another core business than waste heat recovery. This can lead to decisions taking long or lead to a reluctance to invest in waste heat recovery. One way to incentivize waste heat owners to engage in waste heat recovery is to make it as carefree as possible for them: e.g. assume all risks as energy company.
- Do not underestimate the needed system innovation: the experience of implementing the low temperature waste heat recovery is limited amongst fitting staff
- It will be difficult to implement a solution implemented in another location, the low temperature installations are situation dependent and it is difficult to “copy paste” solutions: be prepared for tailor making the solution
- When contractual arrangements are needed to access the low temperature heat source it is important to remember that non-standardized solutions tend to involve a large number of stakeholders. This complicates the contract: keep the number of contractual parties limited.
- Permits are many and rigorous in some contexts, like the metro tunnel. It can be difficult to access the tunnel to make the installation and to maintain it. The best time to install metro heat recovery is when a station is built or rebuilt.
- The heat pumps in the systems necessitate electricity. Consider hedging the electricity price or perhaps install PV for operating the heat pumps independently of electricity price.
- Urban waste heat recovery is largely unknown amongst users. Therefore, awareness creation is important to generating a demand for this kind of solution. Inform users that they can require a green heating supply and given them the possibility to actively choose it.

4. Comparison between low-temperature heating and other alternative heat sources

This chapter presents a calculation tool developed by ReUseHeat and the results obtained by applying that tool to compare the costs of different heat supply options from the perspective of the household owner. It is the result of discussions at consortium meetings about the need to compare low-temperature investments with other heating alternatives.

When studying the benefits of LTDH, it is crucial to appropriately contextualise them. In other words, the advantages and disadvantages of establishing LTDH should be compared to other heating alternatives, namely high-temperature DH and individual heating solutions. There are at least two perspectives that can be chosen for the comparison: 1) a "social planner" perspective that compares alternative heat supply options from a societal point of view, i.e., tries to identify the solution with the best outcome for all parties involved and 2) a user's perspective that compares alternative heat supply options solely from the perspective of a household owner.

This chapter presents a calculation tool developed by ReUseHeat and the results obtained by applying that tool to compare the costs of different heat supply options from the perspective of the household owner, i.e., approach 2 as described above. The calculations in the analysis are done under the assumption that the house lacks an existing heat supply option (neither DH nor individual). This can also be viewed as a case where the existing heat supply in the area has reached its technical lifetime and needs to be replaced.

The results of the analysis show that both high- and low-temperature DH connections are cost-competitive heating alternatives in the three investigated, ReUseHeat demonstrator, countries. In fact, the LTDH connection is the least expensive heating solution in Germany and Spain. Natural gas-fired boilers are in direct economic competition with DH connections (gas price at level before Ukraine crisis). Other heating alternatives require reductions in either capital or operational costs (via reduced fuel prices or taxes) to become cost-competitive against DH and gas-fired heating options.

4.1 Tool description

The analysis is intended to examine whether LTDH is cost-effective and competitive compared to high-temperature DH and individual heating technologies. This analysis compares the levelized cost of heat (LCOH) estimations calculated for each heating solution. The LCOH reflects the average yearly price of heat for the household owner to establish and operate either an individual heating solution or a DH connection. In this study, LCOH is calculated with an Excel-based calculation tool (hereafter referred to as the Tool) based on Equation 2:

$$\mathrm{LCOH} = \frac{\sum_{t=0}^{T}\left(\frac{\mathrm{C\_Inv_t + C\_O\&M_t + C\_fuel_t + C\_tax_t + C\_env_t}}{(1+r)^t}\right)}{\sum_{t=0}^{T}(\mathrm{MWh_t})} \qquad \text{Eq. 2}$$

where $\mathrm{C\_Inv_t}$ is the sum of all capital expenditures, $\mathrm{C\_O\&M_t}$ is the sum of operation and maintenance costs, $\mathrm{C\_fuel_t}$ is the cost of fuel, $\mathrm{C\_tax_t}$ is the sum of all taxes paid and $\mathrm{C\_env_t}$ is expenditures related to the environmental impact of the heating solution, all in year t. $(1+\mathrm{r})^{\mathrm{t}}$ is the discount factor in year t with the discount rate r. $\mathrm{MWh_t}$ is the total amount of heat supplied to the household by a heating solution in year t.

The capital expenditures include both the investment cost (unit, installation, and commissioning) of the heating equipment (for the DH connection, the cost of the heat exchanger) and the cost of connecting the solution to the house. The operation and maintenance (O&M) costs include fixed and variable costs as well as the capacity fee; for example, in Sweden, customers connected to DH pay not only for consumed heat but also for the maximum instantaneous power of the heat supply – the capacity fee.

The capacity fee reflects the cost, which the DH provider carries for having the required capacity available for its consumer. The fuel cost for a) gas- and biomass-fired boilers is the price of gas and biomass, respectively; b) for electric heaters and heat pumps is the price of consumed electricity and c) for customers connected to high- and low-temperature DH is the cost of heating that the homeowner pays for the consumed heat. The environmental cost is the cost for the emitted CO_2, i.e., the emission factor for the fuel, electricity or DH is multiplied by the price of CO_2 and the fuel consumed for generating the required heat. The assumptions made in the Tool for the performed analysis and the input data are explained and available in Appendix 3.

4.2 Results

This section presents and discusses the LCOH estimations calculated using the developed Tool for the analysed heat supply options (individual and DH connections) for the three countries hosting the ReUseHeat demonstration sites: Germany, Spain and France. The reader must keep in mind that the presented results greatly depend on the assumed input parameters and the specifics of the Tool and, hence, these results should only serve as valuable insights and the beginning of a deeper, more thorough analysis Germany, Spain and France.

The overall outcome of the analysis (Figure 26 – 28) is that connecting a house to a LTDH system is competitive for the homeowner when compared to the high-temperature DH connection or individual heating solutions. The LTDH connection was found to be the cheapest heating option in Spain and Germany, with the LCOH estimations being 67 €/MWh and 75 €/MWh, respectively. In France, the LCOH of the low-temperature DH connection is noticeably higher at 89 €/MWh, due to noticeably high capacity-fees applied to DH consumers (more details below). The results also show that natural gas-fired boilers are the main competitors to DH connections. The LCOH estimations calculated for air-to-water and brine-to-water heat pumps (HP) options show that these technologies will result in higher expenses for the household owner than the DH and natural gas heating options (again not in France). Electric boilers have the highest LCOH in all of the countries due to the high expenses of electricity purchase and taxes.

4.2.1 Germany

The results show that connecting a house to a high- or low-temperature DH system in Germany (Figure 26) will likely result in similar costs for the household owner as having a natural gas-fired boiler. The main difference in the cost structures of these technologies is that the DH connections will have higher initial expenditures, i.e., a higher investment cost, while a natural gas-fired boiler will result in higher operational costs due to higher taxes and environmental costs. The LCOH estimations for biomass- and oil-fired boilers indicate that these technologies are in close competition with natural gas-fired boilers and DH options. The analysis shows that installing either an air-to-water or a brine-to-water HP in Germany can lead to around 50% higher expenses for the household owner compared to the DH connections. This is mainly due to the high electricity prices and energy taxes for households in Germany. For the same reason, electric boilers are not economical for heating in Germany.

4.2.2 Spain

The analysis shows that establishing a DH connection to a house in Spain (Figure 27) bears a similar LCOH for the household owner as installing a natural gas-fired boiler. The difference in the cost structure of these options is the same as noted for Germany: higher capital costs for DH connections but higher operational costs for a natural gas-fired boiler. The cost of having a HP, either an air-to-water or a brine-to-water, is lower in Spain than in Germany. This is due to lower electricity prices and energy taxes in Spain. Yet having a HP will still result in higher expenses for the household owner than a natural gas boiler or a DH connection. An electric boiler is also the most expensive heating option in Spain, as in Germany.

The LCOH estimations for the DH connections in Spain are lower than in Germany. This is due to the assumption that the capacity fee is not applicable to DH consumers in Spain as in Germany. Hence, the O&M share of the cost structure of the DH connections is smaller in Spain than in Germany .

4.2.3 France

Note: *input data for the high- and low-temperature DH connections of a single-family house in France could not be found and, hence, the presented results for the DH connections are based on the input data relevant for a multi-family house.*

Our results indicate that the cheapest heating option in France (Figure 28) is a natural gas-fired boiler. Yet, the biomass-fired boiler, air- and brine-to-water HPs and low-temperature DH connection are in close competition to the gas-fired boiler option, i.e., the LCOH estimations for the indicated heating solutions are higher than the LCOH of the gas boiler by no more than around 10%. Air- and brine-to-water HPs are cost-competitive heating options in France due to its lower electricity prices and taxes than those in Germany and Spain. In France, the DH connections have lower shares of capital costs incorporated into their cost structures than in the other two countries whereas the share of the O&M costs is noticeably larger. This is due to the assumption that the cost of the heat exchanger (i.e., the "single unit investment" parameter) is included in the connection cost, which is accounted for in the O&M costs estimation. It is also worth mentioning that the VAT rate for DH systems (as well as for district cooling systems) with more than a 50% share of renewable energy sources in the generation mix is reduced from 19% to 5.5% in France. If the 5.5% rate is applied, the LCOH estimations for the high- and low-temperature DH connections can be reduced to 94 €/MWh and 85 €/MWh, respectively.

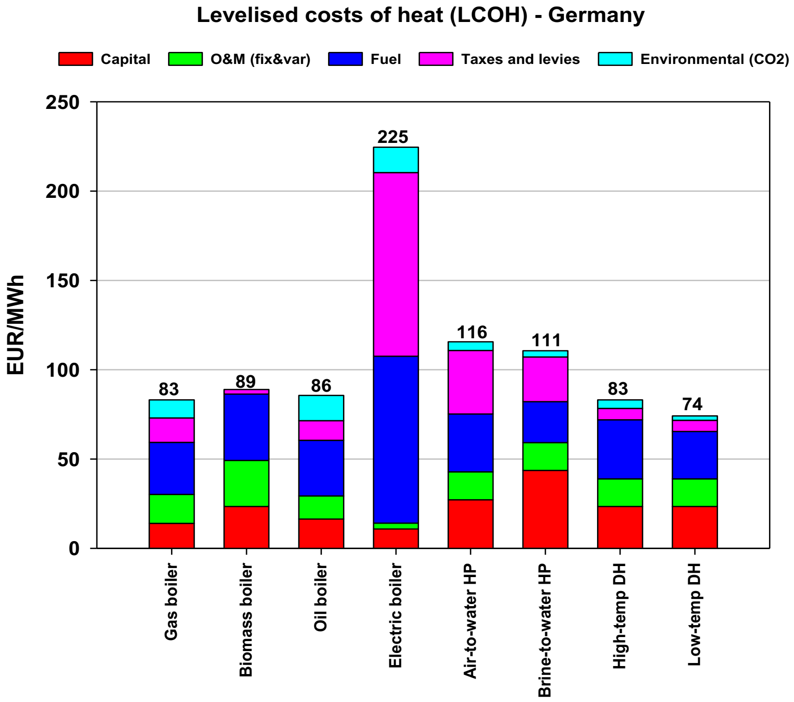


Figure 26. The LCOH estimations calculated using the developed Tool for all of the analysed heat supply options for Germany.

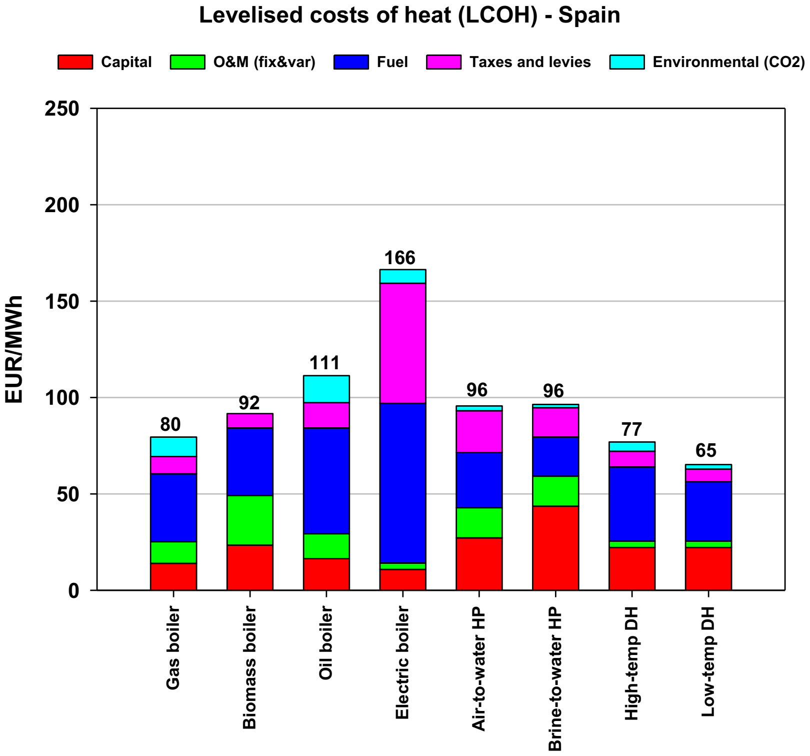


Figure 27. The LCOH estimations calculated using the developed Tool for all of the analysed heat supply options for Spain.

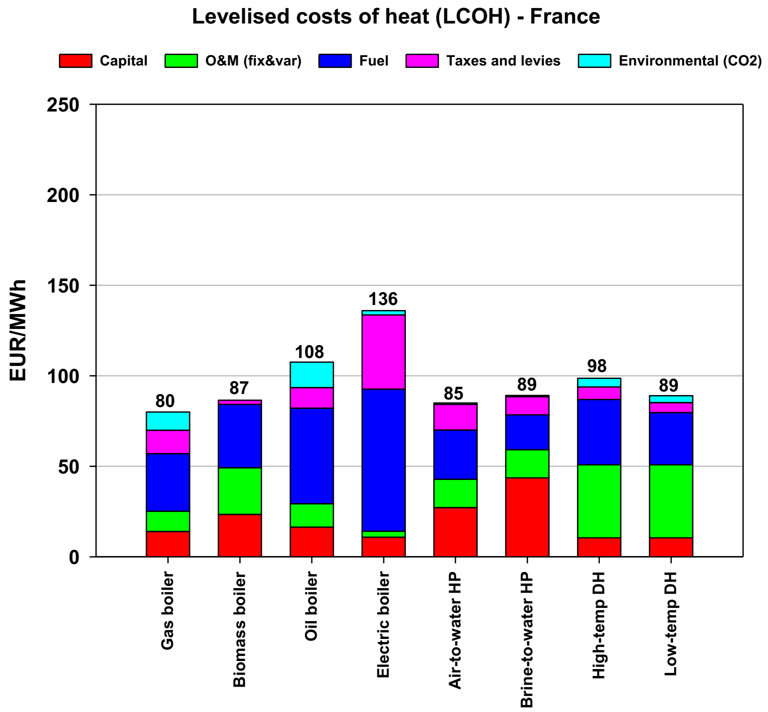


Figure 28. The LCOH estimations calculated using the developed Tool for all of the analysed heat supply options for France.

Discussion
Natural gas-fired boilers, which are shown to be the main competitor to the DH connections, are under a tough pressure in the current realities. There is no consensus if natural gas can be perceived as a bridging energy source on the way to carbon-neutral future or if it should be treated as the rest of fossil fuels. If the later, natural gas-fired boiler will not be a viable, long-term heating solution anymore. For example, in Germany, a houseowner is no longer allowed to install a natural gas-fired boiler as a single measure, a natural gas-fired boiler can only be installed together with solar thermal or in combination with thermal insulation.

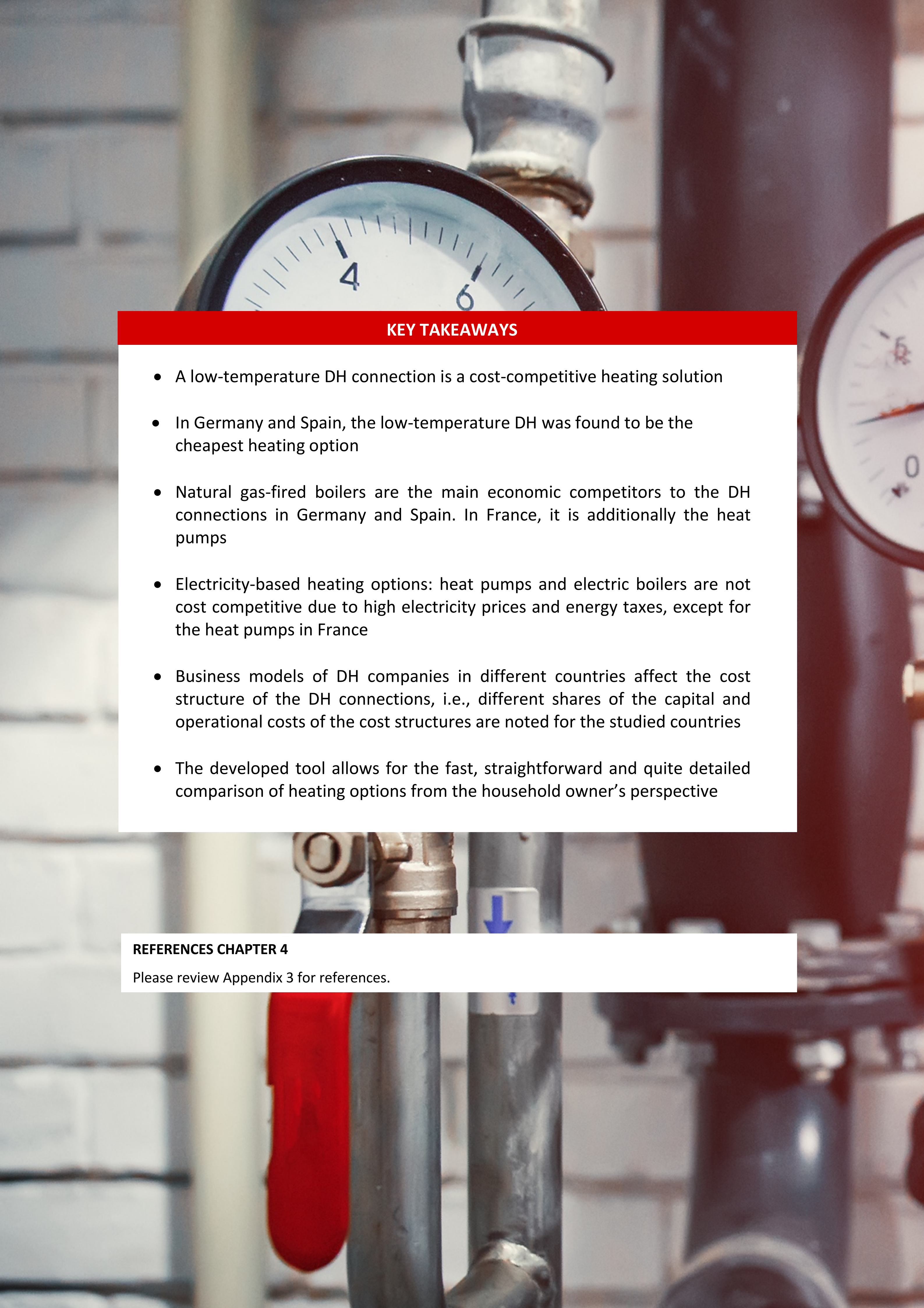
HPs have a great potential to become the main heating source for houses located in areas with low density of the building stock. However, noticeable reductions in electricity prices and/or in energy taxes should take place for HPs to become economically attractive (although, in France, they seem to be competitive already). Reductions in capital costs can also lead to better competitiveness of HPs.

Biomass boilers are not much more expensive compared to the natural gas and DH options, especially in Germany and France. If the price of biomass gets lower, biomass-fired boilers can become the cheapest heating alternative. But, given the projected demand for biomass from other sectors of the economy, the decrease in the price of biomass is not likely to happen.

Additionally, the assumptions and simplifications made in the Tool obviously affected the outcomes of the analysis. It was assumed that the size (capacity) and lifetime of the investigated heating options are the same: 20 kW and 20 years. In reality, these parameters can take different values. For example, houses with electric heating without a hot water storage will likely require a boiler/HP with capacity greater than 20 kW to cover instantaneous demand for hot water. Fuel-fired heating technologies: gas, biomass, and oil boilers, can have lifetimes lower than 20 years. Larger heating units with shorter lifetimes will result in higher LCOH values and, apparently, affect the competitiveness of heating options.

It has also been assumed that the system boundary of our analysis lays at the customer's heat exchanger, i.e., no assumptions on the composition of the DH system, availability of the DH network or density of the building stock in the area where the house is located are included in the Tool (see Appendix 3). Whereas in reality, these parameters will have major impact on the connection cost and price of heating for the DH customers. Hence, the competitiveness of the DH connections can get noticeably greater or lesser, compared to the results shown above, depending on the assumptions made for the DH system and the location of the house.

There are also other inputs/assumptions that can greatly affect the outcomes of the analysis and which should be assessed, e.g.: a) capacity (network) fee applicable to gas and electricity connections (and not only to DH connections, as we assumed in our analysis), b) development between and variability within years of the electricity prices, as well as other fuels, c) uncertainties in the price of CO2 and other pollutants (which are currently not included in the Tool) in the future. These and other assumptions the reader is greatly encouraged to test in the Tool to draw his/her own conclusions from the performed analysis.



KEY TAKEAWAYS

- A low-temperature DH connection is a cost-competitive heating solution
- In Germany and Spain, the low-temperature DH was found to be the cheapest heating option
- Natural gas-fired boilers are the main economic competitors to the DH connections in Germany and Spain. In France, it is additionally the heat pumps
- Electricity-based heating options: heat pumps and electric boilers are not cost competitive due to high electricity prices and energy taxes, except for the heat pumps in France
- Business models of DH companies in different countries affect the cost structure of the DH connections, i.e., different shares of the capital and operational costs of the cost structures are noted for the studied countries
- The developed tool allows for the fast, straightforward and quite detailed comparison of heating options from the household owner’s perspective

REFERENCES CHAPTER 4

Please review Appendix 3 for references.

5. The future

In this section, the wider policy environment and its implications for urban waste heat is reflected upon (5.1). Thoughts on district energy in the future are provided (5.2), the chapter is concluded with the three major learnings from ReUseHeat (5.3).

5.1 Policy implications

The dominant policy matter is climate change. This has two strands: international developments around the Paris Agreement and the EU Green Deal, the former influencing the latter. On 15 January 2020, the European Parliament voted to support the Commission's "European Green Deal", which contains an outline roadmap [1,2]. Most details need to be firmed up, where the Taxonomy is one important piece. Apart from correct interpretation of DHC under the Do No Significant Harm Criteria there are a number of open factors to consider in the taxonomy. Such items include classification of bioenergy, waste to energy and waste heat.

On 21 April 2021, an initial agreement for a European climate law was agreed upon in the EU. This is great news and much needed for continuous work towards carbon neutrality. The EU aims to be climate neutral by 2050, which is achievable if ambitious targets are met along the way (like the revised 2030 reduction target of at least 55% of CO_2 emissions compared to levels in 1990). The new reduction target increases the required rate of reduction by more than five times compared to the previous 2020 target. Hence, in the nine years to come, increased decarbonisation activity must occur, which will necessitate full-speed progress on activities that support the circular economy plan first launched in 2015.

Terminology is important to understand the plans. In addition to "road map", one finds "Energy Transition Maps", "measures", "pathways", "impact studies" and so on. Some of the best road maps are to be found at the city level. A very brief summary of the situation regarding DHC is that it is well-developed compared, for example, to hydrogen. Several successful EU projects with many individual demonstrators support the conclusion that DHC has not only come of age but may be considered a strong movement with a definite role in the climate change agenda [3], although one not fully worked out. LTDHC is a branch of this.

We believe awareness of the energy policy developments is important, on the positive side, to draw on much freely available advice and, on the negative side, to understand how outside policy may adversely affect local decisions on technology, economics, social and environmental development. For example, they may have serious implications for long-term contracts and need to be incorporated into scenarios, sensitivity and risk analyses at the feasibility and contract stages of LTDHC installations. Contracts will need to be made more flexible and dynamic, incorporate more monitoring and handle unforeseen events such as sudden changes in regulation and increased volatility in funding, pricing and demand.

From all of the UN and EU material, it is possible to extract a version of the future that will affect planning in DHC. This was clearly stated in public in a speech by Frans Timmermans, vice president of the EU and director of the Green Deal. His full speech is in [2]. Here are three of his messages:

> (i) "At the end of that road [to 2050], there will be no more space for coal, very little room for oil and only a marginal role for fossil gas."
>
> (ii) "We need to double our building renovation rate to make our homes more efficient and reduce our energy use."
>
> (iii) "…electrification is our end-game in many areas. It is the fastest route to decarbonisation for most, and the most energy-efficient solution in many end-use sectors."

The fact that the world and Europe are at a critical make-or-break point regarding global warming must focus the minds of those developing new DHC projects. Gas will eventually be terminated, and LT sources attached to HPs and other sources, such as geothermal, will be more important, as will the relationship between national electricity grids and local renewable heat production at the city and community levels. Heat storage, still much cheaper than electricity storage, is likely to be critical. Re-fitting the insulation of older buildings is a necessity, as stated in many documents, and regulations for new buildings are becoming tighter. It is cathartic to follow the increased urgency in energy policy represented by the switch from the traditional "keeping-the-lights-on" ethic (although security remains important) to a zero net carbon agenda.

Against this backdrop ReUseHeat partners find that it is clear that LTDHC should be playing an increasingly important role in the wider policy environment.

5.2 District energy in the future

Future heat supply
In the future, say, 2050, incineration will likely be limited. There will be no incineration of fossil fuels, access to residuals from forestry will be limited as it will have other offsets than incineration and waste volumes will be minimised (as a result of the circular economy). The future heat sources will be natural (solar, geothermal, water and air) and residuals from different processes (industrial, urban infrastructure and others). Most likely the residuals from industry will lower over time, as a result of increased process efficiency but some waste will remain. Also, it is probable that new industrial processes that generate waste heat will appear, one such example that is detectable is the production process of hydrogen.

The future heat sources are limited in terms of location and size. Location-wise, geothermal wells, lakes and heat generating processes are inherently local and panels for solar heat recovery are limited to where there is space to place them. In terms of size, the sources are constrained and cannot be increased to match a peak in heat demand. In an existing DHN context, usage of locally available heat sources can be achieved by keeping the network as a backbone to which local heat sources are added. In a new DHN context the locally available sources will be decisive for its' setup. Depending on the heat sources used, it is likely that some networks will be warmer, and some will be colder than others.

Decentralized heating system and storage in focus
Making use of these heat sources will necessitate a business logic other than large-scale heat recovery (from CHP generation, for example) or heat generation (from incineration in boilers) distributed through city-wide networks. District energy providers' main activities will be to store heat and provide it on demand

Win-win solutions
In 2050, when carbon neutral heating and cooling supply is standard, shared incentives will not be directed towards cutting Co2 emissions but rather towards maximizing the value of flexibility. In terms of customer offers, an important selling point of DHC will be a win-win solution for energy providers, customers and prosumers.

Investments have been made to establish partnerships with customers and owners of waste heat. Customers can choose active engagement in their heat and cool provision and facilitate the harvest of different flexibility gains (like shifting heat or cool usage away from peak load (by agreeing to lower indoor comfort for shorter time periods and other) if compensated. Most likely not all customers will choose to be actively engaged but the option to be so is likely to be part of any DHC offer.

Waste heat owners are often already district energy customers (prosumers). In 2050, their collaboration and integration into the DHN is imperative and reflects the business logic of decentralized heat supply. There are many possible prosumers. Examples in the urban context are data centres, service sector buildings, sewage water networks, metro systems (all covered by the ReUseHeat project) and food stores as well as industrial companies with heat-generating processes. One important, future prosumer is the building owner. In current networks, buildings are passive components where interaction with the grid is limited. Future buildings will be flexible components in the system that can be used for things like peak load shaving, storage and prosumers.

Equipment and staff
To establish the decentralized heat recovery, investments in equipment will be necessary (for example, heat pumps to ensure efficient temperature levels of low-temperature heat sources, storage anddigital infrastructure). Also, staff ensuring the direct and close customer relationship is key apart from technically oriented staff.

District energy in the future
To conclude, the future district energy system will be heavily reliant on locally available heat sources. A decentralized business logic will dominate and the core business of DHC companies is to harvest locally available heat, store it and deliver it upon demand. Green heating and cooling and digital infrastructure is standard. Customers can actively contribute to the heat supply and prosumers are important to secure heat supply.

In this future, urban waste heat recovery is standard.

5.3 Three major learnings from ReUseHeat

The technology of DH is mature. CHP, HPs, heat exchangers, heat storage and insulated water pipes are not news. For low-temperature waste heat, the technological understanding is increasing as new sources are exploited: metros, sewers, data centres etc. become the subjects of more pilot demonstration projects. There is always scope for better integration, optimisation and control of systems, but the basic technology is in place.

The DH market is immature. A result of different countries being at different stages of heat market development, energy transition and ownership traditions. This variation of maturity extends into finance and economics. The first major learning of ReUseHeat is:

Technology is not the main stopper of urban waste heat recovery. Rather, it is the low level of maturity amongst necessary stakeholders to realize the opportunity, to identify who to collaborate with and how.

Energy transition is global but practical decisions occur at the local level. This is why the work that cities do is so important, reflected by UN goal #11, “sustainable cities and communities”, and different initiatives like “100 climate-neutral cities by 2030 by and for the citizens”, launched by the EU in 2020. One important way forward is creating efficient climate goals with enlarged shares of renewables in the energy mix, active disinvestment plans for fossil-powered units and increased energy efficiency (reflected, for example, in the ambitious Climate Plan of Copenhagen and the Sustainability Goals of Singapore). Goals are, however, commonly difficult to meet because existing legislation tends to be based on current operations rather than on facilitating new and future solutions. The second major learning is:

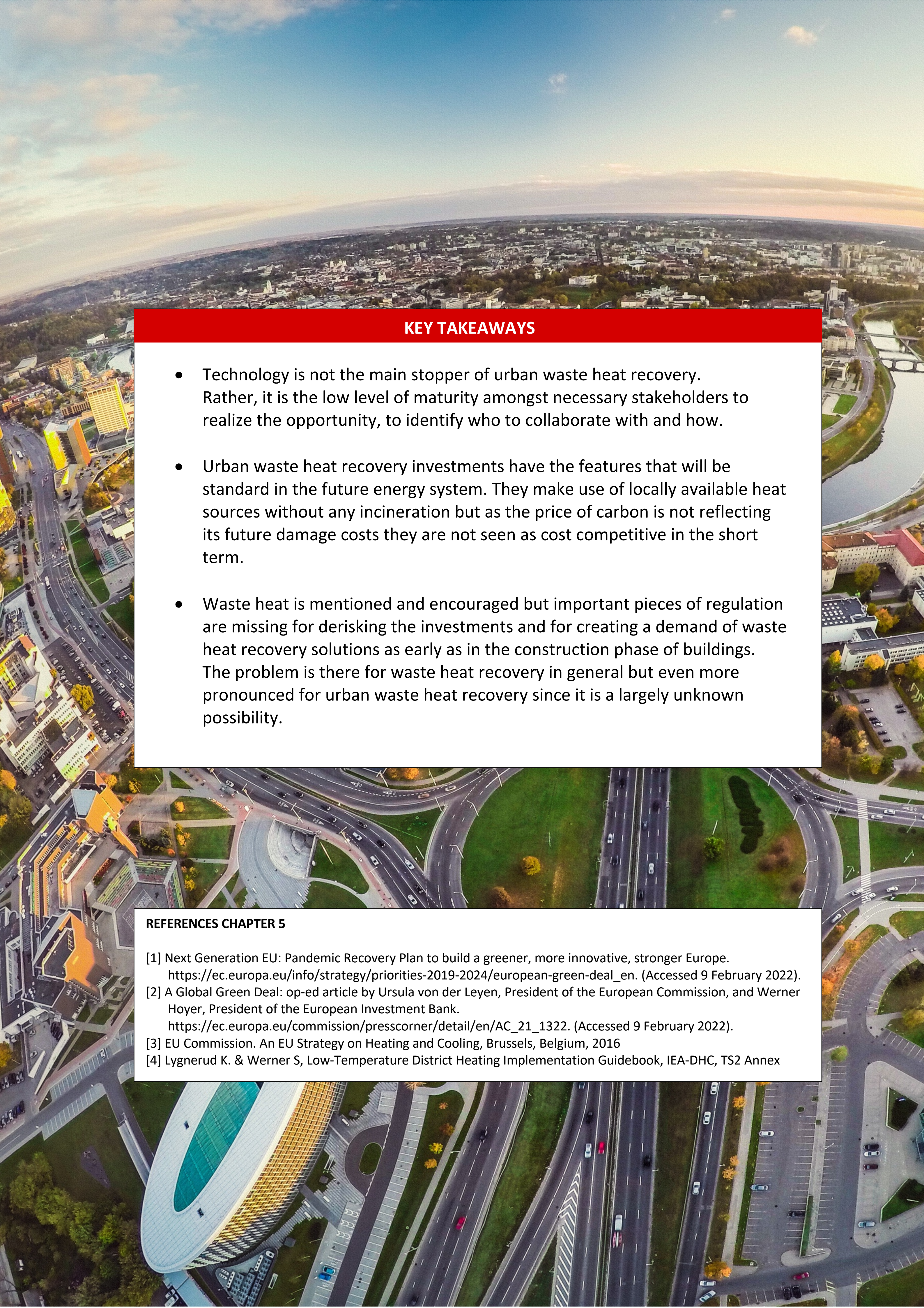
Urban waste heat recovery investments have features that will be standard in the future energy system. They, for example, make use of locally available heat sources without any incineration but as the price of carbon is not reflecting its future damage costs they are not seen as cost competitive in the short term.

So far, more than 160 low-temperature heat recovery implementations have been identified worldwide in an international project focusing on low-temperature implementation: the IEA-DHC collaboration [4]. This number confirms that low-temperature installations are increasingly relevant in many different parts of the world. The investments are, however, competing with incentivized investments in renewables and come in with long-payback periods as a result of the current cost of carbon. DH has been around for long and can be seen as a mature technology. However, the next generations of DHC, that are not reliant on incineration in a centralized heating system are not.

The absence of a legal framework on waste heat in the EU is adding risk to any waste heat recovery investment as it arises questions about the investment. Is an investment in waste heat recovery comparable to an investment in a renewable heat source?

Urban waste heat recovery is new and the awareness about it is low. There is not any efficient market where customers demand the low temperature heat. Given that urban waste heat recovery can greatly support the energy transition it is important to identify what it is and promote it both at the national and local level. Easy measures for local implementation are to include waste heat recovery an integral part in construction processes of official buildings. Whenever a school, a hospital or any other public building is being planned urban waste heat recovery analysis could be integrated. The third major learning is:

Waste heat is mentioned and encouraged but important pieces of regulation are missing for derisking the investments and for creating a demand of waste heat recovery solutions as early as in the construction phase of buildings. The problem is there for waste heat recovery in general but even more pronounced for urban waste heat recovery since it is a largely unknown possibility.



KEY TAKEAWAYS

- Technology is not the main stopper of urban waste heat recovery. Rather, it is the low level of maturity amongst necessary stakeholders to realize the opportunity, to identify who to collaborate with and how.
- Urban waste heat recovery investments have the features that will be standard in the future energy system. They make use of locally available heat sources without any incineration but as the price of carbon is not reflecting its future damage costs they are not seen as cost competitive in the short term.
- Waste heat is mentioned and encouraged but important pieces of regulation are missing for derisking the investments and for creating a demand of waste heat recovery solutions as early as in the construction phase of buildings. The problem is there for waste heat recovery in general but even more pronounced for urban waste heat recovery since it is a largely unknown possibility.

REFERENCES CHAPTER 5

[1] Next Generation EU: Pandemic Recovery Plan to build a greener, more innovative, stronger Europe. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en. (Accessed 9 February 2022).

[2] A Global Green Deal: op-ed article by Ursula von der Leyen, President of the European Commission, and Werner Hoyer, President of the European Investment Bank. https://ec.europa.eu/commission/presscorner/detail/en/AC_21_1322. (Accessed 9 February 2022).

[3] EU Commission. An EU Strategy on Heating and Cooling, Brussels, Belgium, 2016

[4] Lygnerud K. & Werner S, Low-Temperature District Heating Implementation Guidebook, IEA-DHC, TS2 Annex

Appendix 1

Private ownership forms for district energy – the UK experience

In the *PipeCo Model*, pipes are sold by the original developer to a different party. The owner of the pipes then charges the developer a fee for their usage. The idea is that the pipes, which have a long lifetime (up to 60 years), and the heat generation infrastructure, which has a lifetime of typically 15 to 20 years, appeal to different kinds of investors. The pipes are generally very expensive to install but require little maintenance and are thus a high-cost-low risk asset with a predictable yield. Such an investment may appeal to a pension fund, for example. At the same time, the original developer is not required to have the large outlay of laying the pipes on its books in the longer term and can spend that money in other places instead. The PipeCo Model can also be beneficial when multiple nearby networks are built and designed to be connected later.

The *AssetCo Model* is very similar to the PipeCo Model but all of the assets are sold by the original developer to third parties who also operate and finance those assets. The original developer is only responsible for retailing heat to customers and pays for the use of the assets. The potential benefit to the AssetCo Model over the PipeCo Model is the further easing of the balance sheet and transference of risk to other parties.

To a district heating developer, both models pose a potential problem in that, to operate as a viable business model, they require many projects to fund, given that they may eventually sell some or all of their assets to third parties. The Carbon Trust's *Regional Framework Model* suggests a way to bring together key partners to build multiple district heating schemes with similar structures. One of the benefits of this model is the opportunity for economies of scale through reduced capital costs, procurement costs and risk. The increased number of projects can also make the investment more attractive for larger investors. The success of the regional framework relies on the existence of enough players in the market to provide adequate competition.

The idea of a *National Framework* is similar to the regional framework but organised through a national coordinator. Under this model, financing and technical partners undergo a process to be recognised under the national framework. Member organisations can then call on those partners, thereby avoiding a costly procurement process. In the United Kingdom, the Government's Heat Networks Delivery Unit (HNDU) provides support to local authorities at the planning stage of proposed district heating schemes (Gov.uk, 2019).

Appendix 2

Guide to writing heat supply contracts

The contractual arrangement between a supplier of waste heat and a district heating company is crucial. This chapter aims to provide guidance on the nature and contents of that arrangement. In particular, a checklist of important points to consider is provided with some discussion of each. Note that waste heat recovery often requires a highly tailored approach and, thus, additional, more specialised clauses may be required.

First, it should be emphasised that contracts of this type should be subject to the professional advice of a lawyer who understands local, national and EU regulations that might be crucial in shaping such arrangements. This is why a specimen contract is not provided and neither do the authors accept any responsibility for the use of legal advice contained in this section.

Note that heat supply contracts with end users are typically bound by established local and national legal frameworks. This is not universally true for waste heat supply contracts in which there is often a complete absence of, or a very limited, legal framework in place. When dealing with contracts, keep in mind that extra regulation may be introduced over the lifetime of the contract and adjustments may need to be made.

The following elements should be considered in waste heat contracts:

1. Timing of the contract

The contract should clearly set out the *date* from which it is effective and its *expiration date*. Conditions for *termination* of the contract should also be laid out.

Notes. Local regulation can affect both the maximum length of the contract and the conditions for termination.

2. Monitoring

Monitoring can be used to ensure that contractual obligations are met. Contracts can also be designed with payments and obligations conditioned on monitored values. If monitored values are used to ensure that agreed conditions are met, details of actions to be taken if they are not met should be clearly stated. This could include the payment of compensation, a reduction in the price paid or a contract renegotiation.

Notes. For a heat supply contract, the price of heat could be conditioned on the temperature of the supply (input) and this is typically underpinned by monitoring.

3. Contract renegotiation and change

Renegotiation of contracts typically occurs when one side is unable or unwilling to complete its contractual obligations. In such a situation, the relevant party will endeavour to renegotiate the contract into a more beneficial or manageable arrangement. The contract should lay out *conditions for renegotiation*, with a focus on the process that should occur if a clause is broken. In some cases, renegotiation at a fixed point might also be beneficial.

(i) In some cases, such as in Germany, the legal length of a contract may be capped and so renegotiation, even if merely a straightforward formality, is necessary. A renegotiation may be appropriate in waste heat recovery contracts if the waste heat provider is no longer able to provide the agreed volume of heat but is willing to continue to provide a lower volume. In such a case, the *marginal cost* of heat to the district heating provider may increase and they may seek to negotiate a lower price per unit.

(ii) *Control systems* may or may not be part of the basic contract. For example, extra control systems may be added after studying the active system or after technological advances or network expansion. It is advisable to reference such changes in the original contract.

4. Renewal terms

All contracts are limited in time and eventually expire. It is beneficial to include clauses that allow for the automatic renewal of the contract subject to one or more agreed conditions.

In a waste heat supply contract, the district heating company may agree to automatic renewal of the contract on the condition that heat was supplied at the agreed volume and temperature for a set proportion of the contract period. This provides an incentive for the waste heat provider to carry out its obligations.

5. Heat supply specifications and units

The *capacity*, *quantity* and *temperature* of waste heat to be supplied should be clearly laid out and, if applicable, linked to the price paid. There may be some small variability in the temperature of the heat provided and thus a *minimum* and *maximum* acceptable temperature over a specified period should be provided.

(i) Units should be clearly stated and chosen according to industry standards. Temperature should be stated in degrees Celsius (°C), units of heat in megawatt-hours (MWh), etc.

(ii) It is important to include some indication of the variability of waste heat supply (e.g., mean, minimum and maximum).

(iii) Efficiency may be referred to in the contract to guard against the promised efficiency of heat transfer being less than predicted.

(iv) There may be a difference between the idealised *coefficient of performance* (COP) provided by the heat pump manufacturer and the actual value achieved. This may be *pending* at the contract drafting stage and so it may be useful for the price of heat to depend on the value achieved in practice and is a further reason for monitoring.

6. Price formulae

The *price* paid by the district heating provider for waste heat is a crucial element of waste heat supply contracts. There are many examples of formulae for the price of waste heat that vary in complexity. In all cases, conditions for payment should be laid out clearly and unambiguously. The main types of formulae are given below:
Waste heat is provided for *free*.

- A *fixed periodic fee* (weekly, monthly or annually) is paid subject to the quality and consistency of supply.
- A fixed *price per unit of heat* is paid subject to temperature conditions. This simplicity is sometimes welcome.
- A *combination* of fixed and variable payments are made.
- Heat is purchased only under certain seasonal or weather conditions (these conditions should be clearly and unambiguously defined).
- End-user demand for heat is highly seasonal and may affect the value of the waste heat to a district heating provider. It may be beneficial to account for this in the contract.

(ii) Demand may be split between *peak load* and *base load* requirements.

7. Payment schedules

If payment for the supply of waste heat is agreed in the contract, schedules for making those payments should be clearly laid out. In the case of fixed fees, it is usually beneficial to agree on regular payment dates in advance. If fees are conditional on certain aspects (such as the outside temperature), the period between that condition being met and payment being made should be clearly stated. Care should be taken to ensure that conditions for payments are written clearly and unambiguously and with carefully chosen units.

8. Ownership and responsibility boundaries

In waste heat recovery, the heat must be transferred from the property of the waste heat provider to that of the district heating provider and there is, therefore, a boundary of ownership and responsibility for infrastructure. This should be fully specified.
One or more heat exchangers are usually required to transfer heat from air to water and the location, ownership and responsibility for maintenance should be clearly laid out.

9. Location and ownership of heat pumps, exchanges and controls

Low-temperature district heating usually requires the use of a heat pump to upgrade the heat to a suitable temperature for use in a district heating network. The need for a heat pump creates a high initial outlay for low-temperature heat recovery and the responsibility for this outlay will be decided by the choice of business model. The ownership and responsibility for the installation and maintenance of the heat pump should be clearly laid out.

Notes. In some cases, care must be taken to separate the heat exchange plan and the source of heat for security, health or safety reasons. Special clauses may be needed to protect the boundary in such cases.

10. Combined heating and cooling

For certain waste heat suppliers, the cooling that is a by-product of the heat pump used to raise the water temperature to supply hot water to, say, a local grid, may also be used to help cool the original unit of supply, such as a data centre. This requires a well-crafted contract, balancing the value both of heating and cooling.
Combined heating and cooling is sensitive to seasonal variation and, in some cases, the heat pump may be reversed.

11. Maintenance

The contract should clearly lay out responsibility and schedules for the *maintenance* of different parts of the infrastructure. Access rights for maintenance should also be agreed upon, if applicable. This should include details of the required warning period before maintenance is conducted and provision for emergency access should be made.
It may be agreed that each party should carry out maintenance of its own property. If this is not the case, clauses should be included stating agreed actions if damage is caused.

12. Equipment failure

The contract should set out details of liability for equipment failure.
(i) It may be agreed that, if the heat pump belongs to the district heating provider and is damaged by the waste heat provider, compensation will be due.
(ii) The expected lifetime of the equipment should be stated along with actions to be taken in the event of early failure.
(iii) An insurance requirement clause may be included that obligates the waste heat provider to hold insurance to cover such eventualities. This will require a separate contract between the waste heat owner and an insurer.

13. Severability

Severability is a provision in a contract stating that, in the event of one or more clauses being broken, the rest of the contract should remain valid. Such a provision can help ensure the stability of a contractual arrangement but can also prevent a party from leaving an arrangement that is no longer beneficial to them.

(i) The enforceability of severability clauses can depend strongly on the jurisdiction. For example, in some jurisdictions, a contract can be declared void if the fundamental nature of the arrangement is changed by the breaking of a clause.

(ii) The inclusion and nature of a severability clause should be discussed carefully with a lawyer familiar with the law of the territory in which the arrangement is made.

14. Connection fees

Presently, low-temperature heat recovery is in its infancy as a technology and contractual arrangements between district heating providers and waste heat providers are bespoke. However, if heat recovery becomes more widespread, it is likely that a “heat market” will emerge in which providers pay a *connection fee* for infrastructure to connect them to the network.

15. Law and Regulation

In any contract of a technical nature, many areas of national and international laws and regulations may need to be referred to in the contract. Here is a generic list.

1. Health and safety
2. Environmental:
    Pollution
    CO_2
3. Contract law
4. Property law
5. Financial:
    financial probity laws and regulations
    taxation and incentive rules
6. Land use
7. Engineering, quality and reliability standards

(i) Changes in regulation are particularly important for low-temperature district heating because frameworks are likely to be developed over the coming years. For example, if regulations were introduced obligating waste heat producers to provide heat for free, this would fundamentally change the relationship. Clauses in the contract should cover this.

(ii) Funding, taxation, incentives and financial clauses are areas of particularly likely future change and contracts should try to account for this likelihood.

Appendix 3

Assumptions and inputs for the calculations of LCOH (the Tool)

The quality and accuracy of the calculated results depend on the inputs and assumptions included in the Tool. The inputs and assumptions included in the Tool can be categorised into three groups: a) general (relevant to all the technologies and all the countries); b) technology-specific; c) technology- and country-specific. All of the inputs and assumptions can be changed by the user.

The general inputs and assumptions included in the Tool: calculations are performed for a single-family house with an average yearly heating demand of 15 MWh, the capacity of the heat generation/supply unit (for the DH connections, the heat supply unit is the heat exchanger on the building side) is 20 kW, the investment year is 2020, the lifetime of the heat generation/supply units is 20 years, the discount rate is 5% and the price of CO_2 emissions is assumed to increase from around 30 €/tCO_2 in 2020 to around 125 €/tCO_2 in 2040 (corresponding to the WEO (World Energy Outlook) estimates for “advanced economies” in the Sustainable Development scenario [1]).

The technology-specific parameters that, in this study, differ among the investigated individual heating solutions but are assumed to have identical values for each investigated country are as follows: investment cost (€/kW), fixed O&M cost (€/yr), variable O&M cost (€/kWh), energy conversion efficiency, and CO_2 emissions factors for biomass, natural gas, oil (tCO_2/kWh of fuel).The values for these parameters assumed in this study are mainly based on the information available in the Danish Technology Catalogue [2] but were also updated based on the data in other sources [3].
The technology- and country-specific parameters included in the LCOH calculations are as follows: fuel/electricity/heat price (€/kWh), capacity fee (€/kW), VAT (€/kWh), other taxes and levies (€/kWh), yearly average CO2 emissions factors of electricity generation applied to electric boilers and heat pumps, CO2 emissions factors of DH-supplied heat (tCO2/kWh of fuel), and investment, fixed, and variable O&M costs for the high- and low-temperature DH connections. The values for these parameters were checked and updated by the ReUseHeat partners in each demonstration site country. The yearly average CO_2 emissions factors of electricity generation in the investigated countries were taken from the dataset compiled by the European Environment Agency [4]. The average CO_2 emission factor of heat generation in the DH systems in Germany was taken from Schuppler et al.'s study [5] and assumed identical in Spain and France. All of the inputs are available in Tables A1, A2 and A3.

To compare the LCOH of high- and low-temperature DH connections, a few assumptions were made. The savings of low-temperature DH systems compared to high-temperature DH systems are unknown. What is known is that the cost reduction gradient is significantly higher for renewable energy sources (like, e.g., waste heat) when the supply and return temperatures in the DH network are low. In the calculation exercise, we assumed that all the savings from establishing a low-temp DH instead of a high-temperature DH (e.g., a higher share of waste-heat utilisation, lower losses in the network and others) would lead to reduced heat prices for the end user. We assume that the price cut may be up to 20%. Similarly, we assumed that the yearly average CO2 emissions factor of heat generation in a low-temperature DH was 50% lower than in a high-temperature DH. This is due to the assumed increased shares of waste heat utilisation and decreased shares of heat generated by fuel incineration in low-temperature DH systems compared to the more conventional settings of high-temperature DH systems. Other parameters applied to the high- and low-temperature DH connections are assumed to be identical in each investigated country (different values may be applied in different countries).

A few notes on the developed Tool:

- the LCOH is calculated from the homeowner's perspective, i.e., the system boundary of the analysis is the house that consumes heat (this means that for high- and low-temperature DH connections, assumptions around, e.g., the energy mix of the DH system or heat density of the area where the house is located are not explicitly included in the Tool but are reflected in the fuel and connection costs),
- the main objective of the Tool is to provide a way to test different assumptions impacting the cost of heating associated with each heating solution rather than to provide solid LCOH estimations,
- the structure of the Tool is flexible (it consists of several Excel tables) and can be adapted to the level of detail required by the user,
- the Tool includes all relevant factors to compare LCOH of different heating solutions but also has several limitations and simplifications, e.g., it includes a yearly average electricity price, which does not reflect hourly real-life electricity price fluctuations (this and other assumptions should be considered when comparing the results),
- the environmental impact of the investigated heating options is considered by multiplying the CO2 emission factor of the consumer fuel/energy by the CO2 price (although private consumers do not participate in the CO2 market and do not bear direct costs for the emitted CO2 emissions),
- the structure and contents of the tool are inspired by other, similar tools but adjusted to the specifics of the ReUseHeat project.

Table A1. The techno-economic parameters assumed to describe the individual and DH technologies in the LCOH calculations performed for Germany.

Technology GERMANY	Unit	Gas boiler	Biomass boiler	Oil boiler	Electric boiler	Air-to-water HP	Brine-to-water HP	High-temp DH	Low-temp DH
Unit size	kW	20	20	20	20	20	20	20	20
Investment year	-	2020	2020	2020	2020	2020	2020	2020	2020
Single unit ivestment	EUR	6440	10740	7515	4965	12485	20000	5320	5320
Single unit fix O&M cost	EUR/yr	255	605	295	65	360	360	80	80
Connection cost	EUR/kW	0	0	0	0	0	0	270	270*
Var. O&M	EUR/MWh	1	1	1	1	1	1	4	4
Fuel / electricity /DH price	EUR/MWh_fuel	43	48	46	150	150	150	50	40
Capacity fee	EUR/kW	6.0	0	0	0	0	0	11.95	11.95
VAT	EUR/MWh_fuel	9	3	10	50	50	50	10	10
Taxes and levies (excl.VAT)	EUR/MWh_fuel	11	0	6	115	115	115	0	0
Fixed O&M	EUR/kW	12.8	30.3	14.8	3.3	18	18	4	4
Total efficiency		0.92	0.8	0.92	1	2.89	4.09	0.95	0.95
Lifetime	years	20	20	20	20	20	20	20	20
Emission factor	kgCO$_2$/MWh_fuel	204	0	285	311	311	311	100	50

* The connection to a low-temperature DH network might be a bit higher compared to the cost of the high-temperature DH connection as there is a higher investment in the infrastructure necessary (larger pipe diameters, etc.). However, this was not considered in our analysis due to the lack of data.

The input data for the calculation of the levelized cost of heat (LCOH) in Germany can be found in [6] – [14].

Table A2. The techno-economic parameters assumed to describe the individual and DH technologies in the LCOH calculations performed for Spain.

Technology SPAIN	Unit	Gas boiler	Biomass boiler	Oil boiler	Electric boiler	Air-to-water HP	Brine-to-water HP	High-temp DH	Low-temp DH
Unit size	kW	20	20	20	20	20	20	20	20
Investment year	-	2020	2020	2020	2020	2020	2020	2020	2020
Single unit ivestment	EUR	6440	10740	7515	4965	12485	20000	6175	6175
Single unit fix O&M cost	EUR/yr	255	605	295	65	360	360	65	65
Connection cost	EUR/kW	0	0	0	0	0	0	200	200*
Var. O&M	EUR/MWh	1	1	1	1	1	1	1	1
Fuel / electricity /DH price	EUR/MWh_fuel	52	45	81	133	133	133	59	47
Capacity fee	EUR/kW	0	0	0	0	0	0	0	0
VAT	EUR/MWh_fuel	11	9	17	40	40	40	12	10
Taxes and levies (excl.VAT)	EUR/MWh_fuel	2.3	0	2.3	60	60	60	0	0
Fixed O&M	EUR/kW	12.8	30.3	14.8	3.3	18	18	3.3	3.3
Total efficiency		0.92	0.8	0.92	1	2.33	2.63	0.95	0.95
Lifetime	years	20	20	20	20	20	20	20	20
Emission factor	kgCO$_2$/MWh_fuel	204	0	285	156	156	156	100	50

* The connection to a low-temperature DH network might be a bit higher compared to the cost of the high-temperature DH connection as there is a higher investment in the infrastructure necessary (larger pipe diameters, etc.). However, this was not considered in our analysis due to the lack of data.

The input data for the calculation of the levelized cost of heat (LCOH) in Spain can be found in [15] – [20].

Table A3. The techno-economic parameters assumed to describe the individual and DH technologies in the LCOH calculations performed for France.

Technology FRANCE	Unit	Gas boiler	Biomass boiler	Oil boiler	Electric boiler	Air-to-water HP	Brine-to-water HP	High-temp DH	Low-temp DH
Unit size	kW	20	20	20	20	20	20	20	20
Investment year	-	2020	2020	2020	2020	2020	2020	2020	2020
Single unit ivestment	EUR	6440	10740	7515	4965	12485	20000	-	-
Single unit fix O&M cost	EUR/yr	255	605	295	65	360	360	-	-
Connection cost	EUR/kW	0	0	0	0	0	0	240	240*
Var. O&M	EUR/MWh	1	1	1	1	1	1	18	18
Fuel / electricity /DH price	EUR/MWh_fuel	47	45	78	126	126	126	55	44
Capacity fee	EUR/kW	0	0	0	0	0	0	35	35
VAT	EUR/MWh_fuel	9	3	15	26	26	26	10.45	8.4
Taxes and levies (excl.VAT)	EUR/MWh_fuel	10	0	2	40	40	40	0	0
Fixed O&M	EUR/kW	12.8	30.3	14.8	3.3	18	18	0	0
Total efficiency		0.92	0.8	0.92	1	2.89	4.09	0.95	0.95
Lifetime	Years	20	20	20	20	20	20	20	20
Emission factor	$kgCO_2$/MWh_fuel	204	0	285	51	51	51	100	50

* The connection to a low-temperature DH network might be a bit higher compared to the cost of the high-temperature DH connection as there is a higher investment in the infrastructure necessary (larger pipe diameters, etc.). However, this was not considered in our analysis due to the lack of data.

The input data for the calculation of the levelized cost of heat (LCOH) in France can be found in [21] – [23].

REFERENCES APPENDIX 3

[1] IEA. World Energy Model. Macro drivers. https://www.iea.org/reports/world-energy-model/macro-drivers. (Accessed 9 February 2022).

[2] Danish Energy Agency. Technology Data. https://ens.dk/en/our-services/projections-and-models/technology-data. (Accessed 9 February 2022).

[3] The-competitiveness-of-district-heating-compared-to-individual-heatingv2. https://www.danskfjernvarme.dk/-/media/danskfjernvarme/gronenergi/analyser/03052018-the-competitiveness-of-district-heating-compared-to-individual-heatingv2.pdf. (Accessed 9 February 2022).

[4] Greenhouse gas emission intensity of electricity generation in Europe. https://www.eea.europa.eu/ims/greenhouse-gas-emission-intensity-of-1. (Accessed 9 February 2022).

[5] Schüppler S, Fleuchaus P, Blum P. (2019). Techno-economic and environmental analysis of an Aquifer Thermal Energy Storage (ATES) in Germany. Geothermal Energy 7:11. doi.org/10.1186/s40517-019-0127-6.

[6] BDEW-Heizkostenvergleich Altbau 2021. Ein Vergleich der Gesamtkosten verschiedener Systeme zur Heizung und Warmwasserbereitung in Altbauten. https://www.bdew.de/media/documents/BDEW-HKV_Altbau.pdf

[7] Kumulierter Energieaufwand und CO_2-Emissionsfaktoren verschiedener Energieträger und –versorgungen. https://www.iwu.de/fileadmin/tools/kea/kea.pdf

[8] https://wp-monitoring.ise.fraunhofer.de/wp-effizienz//download/wp_effizienz_endbericht_langfassung.pdf

[9] https://wp-monitoring.ise.fraunhofer.de/wp-effizienz//download/wp_effizienz_endbericht_langfassung.pdf

[10] https://www.zukunftsheizen.de/brennstoff/zusammensetzung-heizoelpreis/

[11] https://www.bmwi.de/Redaktion/DE/Artikel/Energie/gaspreise-bestandteile-staatlich.html#:~:text=Die%20Energiesteuer%20(Gassteuer)%20f%C3%BCr%20die,und%20flie%C3%9Ft%20in%20den%20Bundeshaushalt

[12] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Electricity_prices_for_household_consumers,_first_half_2021_v5.png#file

[13] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Natural_gas_prices_for_household_consumers,_first_half_2021_v1.png

[14] https://www.agfw.de/index.php?eID=tx_securedownloads&p=345&u=0&g=0&t=1639643094&hash=660d507705dfd338b21553e866f0276693f04beb&file=/fileadmin/user_upload/Wirtschaft_u_Markt/markt_und_preise/Preisbildung-_Anpassung/2019_AGFW_Preisuebersicht_Webexemplar.pdf

[15] https://www.boe.es/diario_boe/txt.php?id=BOE-A-2020-11426

[16] http://obsbiomasa-precios.itg.es/energySources

[17] https://datosmacro.expansion.com/energia/precios-gasolina-diesel-calefaccion/espana

[18] https://www.mincotur.gob.es/es-es/IndicadoresyEstadisticas/BoletinEstadistico/Energ%C3%ADa%20y%20emisiones/4_12.pdf

[19] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Electricity_prices_for_household_consumers,_first_half_2021_v5.png#file

[20] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Natural_gas_prices_for_household_consumers,_first_half_2021_v1.png

[21] https://librairie.ademe.fr/energies-renouvelables-reseaux-et-stockage/818-reseaux-de-chaleur-et-de-froid-etat-des-lieux-de-la-filiere-marches-emplois-couts.html

[22] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Electricity_prices_for_household_consumers,_first_half_2021_v5.png#file

[23] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Natural_gas_prices_for_household_consumers,_first_half_2021_v1.png

Coordinated by:

ivl
SVENSKA MILJÖINSTITUTET

Project partners:

AALBORG UNIVERSITY
DENMARK

GEE
GRUPO EMPRESARIAL ELECTROMÉDICO
ASIMESA

BS ENERGY

[TECHNOLOGY CENTRE] CARTIF

CSTB
le futur en construction

DANSK FJERNVARME

DHC+
TECHNOLOGY PLATFORM

eDF

HÖGSKOLAN I HALMSTAD

MÉTROPOLE NICE CÔTE D'AZUR

Naturgy

LSE
THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE

Metroul
PROIECTARE ȘI CONSULTANȚĂ

OCHSNER
HEAT PUMPS

RINA CONSULTING

TRACTEBEL
ENGIE

VEOLIA

www.reuseheat.eu