DISCUSSION PAPER

The barriers to waste heat recovery and how to overcome them?

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Contents

Introduction

Why recover waste heat?

Heating and cooling accounts for around half of the energy consumed in the European Union (Heat Roadmap Europe[1]). Despite significant and essential measures aimed at reducing demand, residential and tertiary buildings, as well as the industry will still need heat and cold. Delivering sustainable heating and cooling solutions to cover this demand is fundamental to achieve Europe's climate neutrality ambition. Studies estimate that there is the potential to expand district heating and cooling to supply 50% of the heat demand, including 25–30% using large-scale electric heat pumps[2].

The EU produces more waste heat than the demand of its entire building stock as underlined in the landmark EU project Heat Roadmap Europe, as well as in the 2016 EU Heating and Cooling Strategy[3]. The study conservatively estimates that waste heat could cover at least 25% of district heating supply[4]. Moreover, there is significant heat recovery potential from unconventional waste heat sources. Indeed, approximately 1.2 EJ (or 340 TWh) per year are possible to recover from data centres, metro stations, service sector buildings, and waste-water treatment plants, which corresponds to more than 10 % of the EU's total energy demand for heat and hot water[5]. However, without adequate recovery solutions, waste heat is released into the atmosphere and its potential lost.

Given the high stakes in play and the severity of the climate urgency, **there is a clear and urgent need for a radical transformation of the energy system in the coming decades**. The deployment of renewables and waste heat used in district heating networks is part of the solution.

Tapping into waste heat sources could displace a significant amount of primary energy demand for heating. It could form an **essential component of a cost-effective energy transition to a smart integrated energy system**, used alongside renewable energy solutions such as geothermal, large scale heat pumps, biomass or solar thermal in district heating networks.

The recovery of waste heat is not a new idea, especially in countries where district heating is well-developed. In Finland, industrial waste heat recovery represents 6% of the heat supplied in DH, while this share reaches 9% in Sweden[6]. **Concrete examples of projects all over Europe exist and show that this is a viable option**. However, due to a multitude of barriers, waste heat recovery is far from reaching its full potential.

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[1] www.heatroadmap.eu
[2] European Commission Staff Working Document in-depth analysis accompanying the Communication on a Long-term Strategy for Europe https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf
[3] European Commission Communication on a Heating & Cooling Strategy https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1575551754568&uri=CELEX:52016DC0051
[4] The legacy of Heat Roadmap Europe, Scenarios, recommendations and resources for decarbonising the heating & cooling sector in Europe and complementing the strategic long-term vision of the EU, https://heatroadmap.eu/wp-content/uploads/2019/02/HRE_Final-Brochure_web.pdf
[5] ReUseHeat project report "Accessible Urban Waste Heat" https://www.reuseheat.eu/project-documents-newsletter/
[6] EHP Country by Country edition 2019; www.euroheat.org/cbc_publications/cbc2019/intro/

Context of this document and considerations

The present discussion paper was drafted by AIT Austrian Institute of Technology GmbH in the context of the delivery of the Urban Agenda Energy Transition Partnership Action 2 on Maximising Waste Heat Recovery in Cities, with the support of Euroheat & Power.

It identifies the challenges and solutions to boost waste heat recovery and served as a basis for the development of the deliverable of Action 2, **a position paper providing recommendations to foster waste heat recovery in cities**.[7]

This process is largely **based on the review of existing documents and literature**. The developed content has also been **reviewed by experts**. Stakeholders from different backgrounds and with various relevant expertise were able to discuss the findings during a workshop and provide written comments.

A workshop took place on 5 March 2020, in Brussels. It gathered over 20 participants from the district heating and cooling sector, city representatives, researchers, waste heat owners, etc. to discuss the identified challenges and feedback into the discussion paper.

The paper takes a **wide approach of waste heat recovery, trying to draw generalities from contrasted national situations**, for instance in terms of penetration of district heating or the share of renewables and waste heat in district heating, or in terms of market regulation. Therefore, the challenges and solutions outlined may or may not be broadly applicable to all countries and individual projects. The same goes for the sources of waste heat, the challenges are not applying uniformly. The authors tried their best to express possible differences without the possibility of being completely granular.

The paper does not structurally distinguish to which specific actors the challenges are applying and does not prioritize the challenges to tackle first. It **gathers examples of successful approaches and projects and exemplifies existing or potential solutions**. Priorities to support more waste heat recovery based on this papers' findings are presented in a recommendations paper.[8]

Boundary conditions: What waste heat sources are considered in this document?

Regarding the terminology used in this document, to keep a consistent approach, the author chose to refer to the term 'waste heat' as used in various EU texts, including the Renewable Energy Directive[9].

Waste heat can be recovered for a company's internal needs, to satisfy heat demand, or through an absorption chiller to cover cooling needs. It can also be injected in thermal networks and distributed to local households and businesses and/or valorised to generate power, usually self-consumed in the installation, substituting electricity from the grid. **In terms of merit order, internal recovery should be**

[7] https://www.euroheat.org/wp-content/uploads/2020/06/Recommendation.pdf
[8] https://www.euroheat.org/wp-content/uploads/2020/06/Recommendation.pdf
[9] Directive (EU) 2018/2001 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC

preferred as much as it is technically and economically feasible, following the energy efficiency first principle.

Waste heat recovery can enable industries to increase their efficiency and decrease their costs while contributing to reduce their environmental footprint. Internal waste heat recovery includes the process-internal re-use of available waste heat for direct use and/or power generation for self-consumption via ORC processes. Heat pumps able to supply temperatures suitable for many processes (up to 160°C and above) are increasingly available[10]. Low temperature waste heat sources can be used to satisfy e.g. space heating demand of office buildings. As a consequence, large quantities of waste heat can often be recovered internally, resulting in a positive effect on the balance sheet of the company, especially if the measures are cost efficient, i.e. due to close proximity of the waste heat source and the demand location.

The present document focuses on the external use of waste heat, meaning the unavoidable waste heat, after all reasonable energy efficiency measures have been implemented, that can be injected in district heating networks and distributed to customers. As part of the Urban Agenda Energy Transition Partnership Action 2, **the paper addresses waste heat utilisation to support the decarbonisation of urban heat supply**.

In general, this paper categorises waste heat into conventional and unconventional.

The first category includes especially energy intensive industries, i.e. glass, cement, paper and metals plants, etc. where waste heat is usually rather readily available, easy to identify and has a high temperature level. For these types of sources, experience of waste heat recovery and utilisation is available in many countries, with some room for improvement and opportunity to generalise such practice.

The second category includes data centres, tunnels and metro stations, as well as cooling from buildings (e.g. offices, hospitals, supermarkets, shopping malls) and waste heat from power-to-gas processes. Another promising heat source for district heating networks is sewage channels and wastewater treatment plants. In this case, besides household sewage water, waste heat from some industries (e.g. food processing) might be relieved into the sewage channel, leading locally to relatively high-volume flows and temperature levels.

For these types of sources, the waste heat potential is less straightforward to identify and often temperature levels are lower. Examples of waste heat utilisation from these sources can be found, particularly in countries where district heating is well-developed, the overall experience with the utilisation on a European level is limited.

The authors of the paper are aware that there is still **unexploited waste heat potential from waste incineration, electricity generation and combined heat and power installations**. However, the paper focuses on less accessible, more difficult to recover, less exploited waste heat sources.

[10] E.g. the DryFiciency project http://dry-f.eu/

Part I – The challenges to waste Heat Recovery

1 – General

The prerequisite to be able to use waste heat externally is the existence of a district heating network. Countries such as the Netherlands or Belgium, where **there are very little district heating networks to connect to**, first require the development of a district heating infrastructure. Also for new build areas, the challenge is to get the buildings connected to the district heating network without having the waste heat supply ensured, on the other hand it is difficult to make a contract with the waste heat owner if the demand is not secured - a **"chicken or egg problem"**. However, the presence of a suitable waste heat source might be a key enabler for developing new DH networks.

From a high-level and policy-making perspective, i.e. for decarbonization strategies on a national or local level, the **identification of waste heat sources** can be a challenge. Data may not be available, especially for unconventional waste heat sources and smaller industries that are not within national or EU centralised online databases linked to permitting procedures and emissions (e.g. the E-PRTR[11]). Moreover, data can be confidential (e.g. for data centres) or sometimes the exact location of the waste heat source does not necessarily match with the company's location (e.g. the registration address of the company could be different to the place where the production plants are located). Some data are only available on a certain raster (e.g. 250 m) thus more detailed investigations are required.

Once identified, the **quantification of the waste heat source** can be a challenge**.** It can be done using different methods, facing individual challenges on the availability and reliability / accuracy of the data:

- Some approaches are using correlation factors between the waste heat potential and public available company data, e.g. to the number of employees. Those correlations have an inherent wide spread and thus little accuracy.
- Concrete historical data / measurements of the waste heat quality are often not available due to the lack of proper sensors or data logging equipment.
- If data on the waste heat source is available, sometimes it could reveal information on the industrial activity (e.g. parameters of production processes). Since some companies are afraid of leaking this information to competitors, it might not be disclosed

The **interest and know-how of a 'waste heat owner' for supplying waste heat to DH networks can be rather low**. In general, waste heat utilisation is neither the core business or competence of the "waste heat owner". The benefits from selling waste heat are not perceived to be matching the costs (investments, human resources, possible impact on main activities). Furthermore, the extraction of waste heat might change the characteristics of the related processes, e.g. due to the installation of heat exchangers, thus resulting in a risk of negatively influencing the core asset and livelihood of the company. This applies especially for high-price and sensitive products, for instance pharmaceuticals, even though, in principle, industrial processes and waste heat recovery systems are decoupled, in order to not affect manufacturing.

[11] The European Pollutant Release and Transfer Register (E-PRTR); https://prtr.eea.europa.eu/#/home

In addition, there are generally little contact and communication opportunities between district heating companies and possible waste heat owners.

2 – Technical

For many waste heat sources, one or more of the following technical challenges for supplying to a district heating network can apply:

1. Temporal mismatch: This concerns both the hourly/daily mismatch and the seasonal mismatch of the waste heat availability, as well as the heat demand in the DH network, also called intermittence. This includes the supply competition between waste heat and most of the renewable heat sources (i.e. geo- and solar thermal energy, ambient heat pumps) as well as waste incineration and other waste heat sources in summer times - also referred to as "heat merit order". Furthermore, instabilities of the waste heat supply might result in challenges for the network controls.

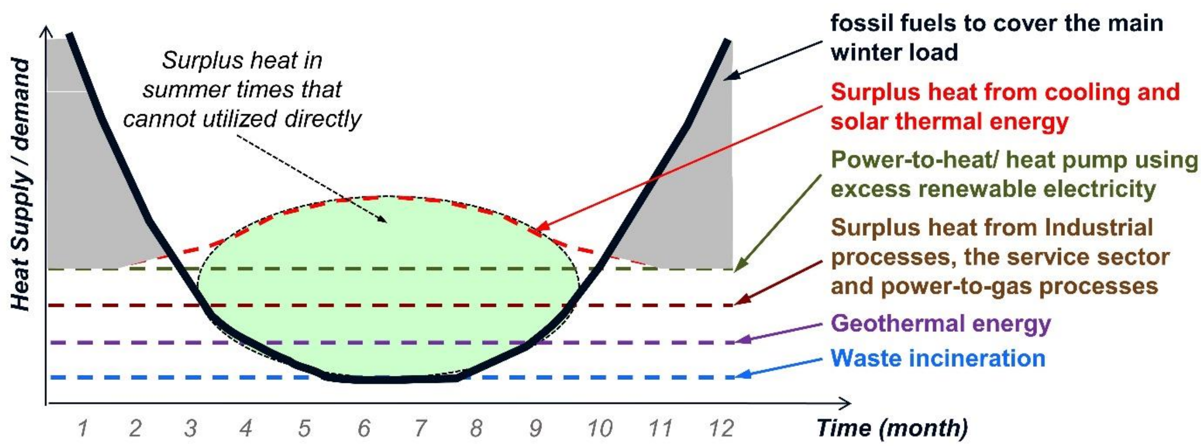

Figure 1: temporal mismatch and summer competition between the different heat sources in district heating networks (source: AIT)

2. Locational mismatch: The DH network does not necessarily extend near the location of the waste heat source and/ or have the required transport capacity for taking up the waste heat. Especially large-scale industries are often located outside the city and DH networks are usually concentrated in dense urban areas. This also applies for larger industrial areas with distributed waste heat sources. Furthermore, major areas of the city might not be connected to the DH network due to the prevalence of alternative heating forms (e.g. gas heating, individual heat pumps), leaving some urban waste heat sources outside the DH area.

3. Quality mismatch: it concerns two different aspects:

a) The temperature level of many waste heat sources is lower than the temperature level of the district heating networks, thus making it impossible to directly feed them into the network. This applies especially for unconventional waste heat sources and "traditional" large scale urban DH networks, that often operate at 100-120 °C supply temperatures and between 45 (best case) and 60 °C (sometimes up to 70°C) return temperatures.

b) Furthermore, some waste heat sources have a relatively small volume and / or have a gaseous form and/ or are based on radiation or convection and/ or are contaminated. Also, the waste heat source might have a discontinuous occurrence, i.e. limited number of full load operating hours. This is requiring a disproportionate effort for harnessing the waste heat.

However, those technical challenges in general can be solved, i.e. a temporal mismatch can be solved by using seasonal thermal storage, a locational mismatch by installing transport pipes (if possible) and a temperature mismatch by installing a heat pump for lifting-up the temperature of the waste heat to the required level or (locally) reducing network temperatures. However, using a heat pump has an impact on the heat price due to non-differentiated electricity grid tariff (see part on legislative obstacles). Although there is still some potential for improving costs, performance and integration of those technologies, the mentioned technical challenges are basically a question of additional investment costs (and in case of heat pumps also operational costs, see section 3). In turn, the technical challenges are directly translating into economic challenges.

3 – Economic and financial

There are long payback periods due to potentially high investment costs for the equipment for waste heat utilisation *(including heat exchangers, equipment for measurement/ monitoring of the waste heat supply and piping for delivering to the transfer point of the DH network, sometimes additional equipment is required, including storages, transport pipes and heat pumps, see technical barriers).* Additionally, revenues from heat sales are rather low, especially in summer, when heat demand is low and other heat sources are competing with waste heat. This results in a low profitability of the investments and high risk due to possible future changes (see below).

A major risk is the **missing long-term guarantees** regarding the future availability and quality of the waste heat supply from the company. On one hand, possible improvements and adaptations of the processes responsible for the waste heat generation, e.g. efficiency improvements, shifting to other processes or changing the product/service portfolio can introduce a risk with regards to availability or quality (temperature level, full load operating hours) of the waste heat. On the other hand, the company might go bankrupt or move to other premises, leaving the investments into waste heat recovery stranded. In turn, DH operators prefer long-term contracts for waste heat delivery, that companies are usually unable to agree on.

Diverging view on amortisation time: industrial companies often are exposed to high market pressure and high return expectations. For Investments outside the core process often minimum amortisation periods between 1 and 7 years are required, with 2-3 years as the most frequently mentioned value. On the other hand, DH companies have a long-term orientation and planning horizon due to the long-term security of the capital reflux from the heat sales (monopoly on the end customer side). This applies especially for DH companies owned by municipalities. Consequently, amortisation periods of ≥ 10 years sometimes up to 20 years and more are often acceptable.

Diverging views on the value of the waste heat: DH network operators usually choose to integrate waste heat if this has a positive effect on their profits and costs. Although it is possible for public companies to work without profit, private companies tend to maximise profits and minimise costs. This could result in a disagreement between the waste heat owners and the DH companies on the price for waste heat supply.

As soon as waste heat reaches a significant share of the supply in a DH network, the network operator has the requirement to install additional heat production facilities as a back-up to cover the risk of unplanned interruptions in the waste heat supply, e.g. due to failure or external events such as heavy weather. This applies especially if very few other production facilities are available, i.e. a DH network is designed with waste heat as a main heat supply. Sometimes, the DH network operator expects guaranteed supply security from the waste heat producer, leaving him with the requirements of additional investments into the back-up. In case the waste heat extraction is providing important cooling services for the company, the installation of back-up cooling equipment is required to bridge temporal limitations for waste heat delivery, e.g. due to technical failures on the DH network side.

Especially for low temperature waste heat, its utilisation relies on the use of a heat pump, which by creating a dependency on the electricity markets and thus increases the uncertainty due to the future development of the price on average and its volatility. Moreover, the waste heat supply usually is difficult to control without changing the process, thus the heat pumps can only operate on the electricity market with additional efforts, e.g. investing into a waste heat storage for decoupling the production processes and heat pump operation.

The utilisation of waste heat may reduce the revenue of the DH company in other areas and may therefore discourage investments. This includes the use of heat from CHP plants that are often owned and operated by the DH utility. This heat is often available in large quantities and thus in competition with the supply of any other (waste) heat source, see also Challenge "temporal mismatch" (Section 2).

Waste heat recovery is often done on a case by case basis, there is no standard solution due to very individual and site-specific boundary conditions, as well as the limited number of real-life case studies, especially for unconventional waste heat sources. This results in high efforts to plan, design and operate systems. Consequently, the engineering and instrumentation efforts and connected costs are relatively high compared to other heat sources. Furthermore, sometimes a higher number of stakeholders or parties needs to be involved, e.g. operators of supporting equipment (e.g. heat pumps and storages), city authorities (e.g. for sewage water channels) or road operators (e.g. for tunnels). This is resulting in additional complexity, and thus increased time and cost. Similarly, the lack of standardised contracts, results in longer contract negotiations since contracts must be drawn up from scratch. There is also the risk of omitting important clauses.

4 – Legislative and regulatory

In general, there are **no regulatory restrictions for the supply of waste heat into DH networks**, since virtually all waste heat supply situations are regulated using bi-lateral contracts between the DH network operator / utility and the company "owning" the waste heat.

Exemptions are sewage water channels and wastewater treatment plants as well as tunnels and subway / metro stations, that are in general in public ownership and important infrastructures. Here, **specific regulations with regards to performance and safety apply**.

District Heating is not regulated as a sector at European level. As mentioned earlier in the paper, market situations, regulatory frameworks for district heating are contrasted in Europe.

For a long time, heat was considered more of a local issue and district heating a local infrastructure. There were nevertheless European texts on energy efficiency and efficient CHP affecting the sector.

The situation has been evolving and heat came into the spotlight. First with the Commission Communication on a Heating and Cooling Strategy in 2016, then followed by the publication of the Energy Package the same year. It became increasingly clearer that the decarbonisation of heating and cooling is key for the energy transition. **EU legislation has now started to incentivise Member States (MS) to step up heating and cooling decarbonisation and recognise the role of waste heat.**

Relevant Text	Article	Content
Renewable Energy Directive (RED II)[12]	**Article 1** (9) Definition	Definition of waste heat and cold
	Article 15 Administrative procedures, regulations and codes	Member States to consider waste heat when planning, including early spatial planning, designing, building and renovating urban infrastructure, industrial, commercial or residential areas and energy infrastructure
	Article 19 Guarantee of origin (GO) for heat	Nothing specifically on waste heat but generally on heating & cooling but waste heat will be concerned when GOs are extended to heat
	Article 23 Mainstreaming renewable energy in heating and cooling	MS can count waste heat towards the renewable heating and cooling target
	Article 24 District heating and cooling	MS should endeavour to increase the share of energy from renewable sources and from waste heat and cold in district heating and cooling

[12] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC

Energy Efficiency Directive (EED)[13]	**Article 2** Definition of energy efficient DHC	'Efficient district heating and cooling' means a district heating or cooling system using at least 50 % renewable energy, 50 % waste heat, 75 % cogenerated heat or 50 % of a combination of such energy and heat;
	Article 7 a & b Energy savings obligation and alternative measures (+ guidance document and annex)[14]	Waste heat recovery is a valid type of alternative measure to fulfil the energy saving obligations
	Article 14 Promotion of efficiency in heating and cooling and **Annex VIII** Potential for efficiency in heating and cooling	Obligation for MS to perform a comprehensive assessment of the potential for efficient heating and cooling including an overview of the heating and cooling market demand, policy measures and a cost benefit analysis of the economic potential for efficiency in heating and cooling, etc.

The new Renewable Energy Directive provides a broad definition of "waste heat and cold":

> *(9) waste heat and cold' means unavoidable heat or cold generated as by-product in industrial or power generation installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a district heating or cooling system, where a cogeneration process has been used or will be used or where cogeneration is not feasible;*

While a broad definition surely serves energy and climate objectives well, there could be some issues.

Waste heat and cold are not considered on par with renewable energy sources, neither in the definition article nor in articles 23 and 24 of RED II, where the accounting of waste heat is subject to restrictions: if Member States decide to count waste heat towards the renewable heating and cooling target, the annual increase for the target goes from 1.1 percentage point to 1.3 (art. 23 (1)). In addition, Member States may count waste heat and cold, but this is subject to a limit of 40 % of the average annual increase (art. 23 (2) (a)).

Waste heat from sewage water is considered as ambient energy and thus as part of the renewable sources, waste heat from tunnels and subways as well as power-to-gas processes is not mentioned directly at all.

Waste heat defined in paragraph 9 can count towards the heating and cooling from renewable targets which is not mandatory while it is not considered as a renewable energy so **it cannot be accounted towards national renewable targets**, unlike waste heat considered as ambient energy.

This might result in an unbalanced treatment of the different waste heat sources when it comes to implementation at national level. Moreover, the higher target when waste heat is included for the

[13] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02012L0027-20200101
[14] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1574946467190&uri=CELEX:32019H1658

calculation of the share of renewable energy in heating and cooling could deter some Member States from including it. The impact of this provision will have to be seen later on, as Member States are still in the implementation phase and the transposition deadline of the Directive is 30 June 2021.

Furthermore, the **term "unavoidable" is difficult to define** since it could relate to technical or economic feasibility. It could also pose difficulties looking into the medium- and long-term future of the waste heat owner, i.e. future technologies might change the process and what was unavoidable to the current state-of-the-art might be avoidable with new technologies (e.g. upcoming of high temperature heat pumps).

The Energy Performance of Buildings Directive (EPBD), as recently amended[15], foresees minimum requirements for the energy performance of new and renovated buildings, including the replacement or retrofit of heating and cooling systems. The calculation of the energy performance is based on primary energy factors (PEF), which values are set by Member States.

In some EU countries, including Belgium and the Netherlands, there could be **difficulties with regards to waste heat and Energy Performance of Buildings due to PEF values**. The electricity used to upgrade the temperature of waste heat is not always renewable and can consequently have a high PEF value. The use of waste heat may then appear unfavourable for the energy performance of a building. In a similar way, if waste heat is recovered from an industrial activity using fossil fuel and a high PEF can be attributed to the waste heat, which appears detrimental to the energy performance of the building. Connecting waste heat becomes meaningless in some cases, as a building will need additional on-site renewables and thus additional investments to meet performance requirements.

In many countries, there are also **indirect barriers for waste heat utilisation** due to support in favour of fossil fuels or a lack of level playing field across the heating sector when individual heating solutions using fossil fuels are **not submitted to any form of taxation on their carbon content.** Denmark has also recently put in place a taxation on waste heat to align with general energy taxation. Moreover, when waste heat temperature is upgraded using a heat pump, there can be an **impact on the heat price due to non-differentiated electricity grid tariff**.

5 – Societal & cognitive

Little awareness of the potentials and the (potential) role for waste heat utilisation in national decarbonisation strategies. In many national energy transition or decarbonization scenarios, waste heat, especially from unconventional sources is not considered at all or plays a minor role. This is mostly due to the electricity and gas centred view of the energy system, accompanied with mostly unsuitable modelling tools not considering the full potential of waste heat.

It is sometimes **difficult to sell waste heat as a sustainable product to end-users and customers**, if the waste heat is related to a fossil fuel driven activity.

For operators, integrating waste heat might result in **extra costs that are difficult to pass to the customer**.

[15] https://eur-lex.europa.eu/eli/dir/2018/844/oj

There is also a lack of understanding from one party to the other party's business and circumstances. waste heat owners and DHC operators usually do not have contact with each other (until they start negotiating the waste heat delivery contract) and there are limited possibilities of **entering a regular dialogue between the DHC operator and waste heat owners**.

Although in recent years, sustainability and green energy is becoming increasingly important and drive the public debate, **it will take more time to mainstream into consumers' habits**, particularly when they must pay more for green products.

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Part II – Solutions and good practices

1 – General

Challenge: Identification and quantification of waste heat sources

Possible solutions and good practice:

➔ Identification on different levels and variety of data sources

- The Comprehensive Assessment of the potential for Efficient Heating and Cooling under the Energy Efficiency Directive, article 14, annex VIII[16], could play a vital role in fostering waste heat recovery by making information about waste heat recovery potential more widely available. Member States are expected to produce their assessment by the end of 2020 following the revised methodology outlined in annex VIII[17] of the EED and associated guidance document[18].

- Significant efforts have been done in recent years in order to create databases for waste heat potentials. There are national and regional studies and scientific articles assessing waste heat potential, to quote only a few:

    - Germany: District heating usage of industrial waste heat (NENIA)[19] from IFEU (in German); Potential analysis "industrial waste heat" from NRW (LANUV)[20] (in German); Industrial waste heat potential in Germany—a bottom-up analysis[21]
    - Czechia: INTERREG E-HEAT Waste heat[22] - Free energy provided analysis and tools to assess and utilise waste heat potential in Central and Eastern European countries, including Czechia.
    - France: Industrial waste heat – ADEME - 2017; Waste heat potential in Ile-de-France Region - ADEME - 2017; Study on the financing of investments for waste heat recovery[23]

- There are also several examples of maps and methodologies created, mostly either on a city/ regional level or in EU co-financed research projects. In general, those projects use officially available data such as large facilities submitted to permitting requirements. One of the most prominent examples is the Pan-European Thermal Atlas (Peta4)[24]. Here, the waste heat from industries is calculated using the emissions database of the European Environment Agency.

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[16] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32019H1659&rid=3#d1e34-108-1
[17] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0826&from=EN
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[21] https://link.springer.com/article/10.1007/s12053-016-9463-6
[22]https://www.interreg-central.eu/Content.Node/CE-HEAT.html#:~:text=CE%2DHEAT%20project%20aims%20to,of%20endogenous%20RES%20%E2%80%93%20waste%20heat
[23] https://www.ademe.fr/sites/default/files/assets/documents/ademe-chaleur_fatale_industrielle-2015-03-pour-lecture.pdf; and https://www.ademe.fr/etude-potentiels-production-valorisation-chaleur-fatale-ile-france; and https://www.ademe.fr/etude-financement-investissements-chaleur-recuperation-industrielle
[24] https://heatroadmap.eu/peta4/

Recently, waste heat sources from metro stations and wastewater treatment plants from the ReUseHeat project[25] have been added.

- Further possible data sources include for example the European Pollutant Release and Transfer Register[26], a map of different industrial plants[27], the IEE project Repowermap[28] as well as an open access free map for data centres (non-exhaustive)[29].

- Especially for identifying smaller and low-grade waste heat sources, a methodology to evaluate and map the potential of waste heat from industry, service sector and sewage water by using internationally available open data has been developed within the project Memphis[30].

- A very different and innovative approach for identification of waste heat potentials has been used in the project HotCity[31]. Here gamification is investigated for collecting data for identifying and locating waste heat sources, i.e. by involving citizens for taking photographs of chimneys and recooling systems, but also by researching on the Internet, conducting on-site surveys, or from Google Maps, etc.

- The Horizon 2020 funded Tasio Project "Waste Heat Recovery for Power Valorisation with Organic Rankine Cycle Technology in Energy Intensive Industries"[32],(Deliverable D2.2 Heat recovery potentials) estimated a theoretical potential of about 2.5 GWe power to be installed, almost 20 TWh of electric energy and up to 7.5 million tonnes of carbon dioxide avoided emissions.

Challenge: Low interest and know-how of the company

Possible solutions and good practice:

➔ Waste heat recovery to improve sustainability credential of waste heat owner

- An increasing number of companies try to mitigate the CO2 footprints. They have adopted strong sustainability goals for their products and processes. However, besides maximizing the onsite generation of energy, the exchange of waste heat becomes increasingly important since it is an important efficiency measure, following the circular economy approach.

- One example is the Austrian "Göss Brewery" that produces carbon neutral beer[33]. This has been achieved by using internal waste heat recovery and installing a solar thermal plant as well as the supply of hydroelectricity and waste heat from a nearby sawmill.

➔ Better communication on waste heat recovery benefits

- The benefits from waste heat recovery should be better communicated to potential waste heat owners: improve energy efficiency, save CO2, boost competitiveness (energy efficiency), foster investments in industrial sector (industrial strategy), boost sustainability (circular economy, SDGs),

[25] https://www.reuseheat.eu/
[26] https://prtr.eea.europa.eu/#/home
[27] https://www.industryabout.com/industrial-maps
[28] https://www.repowermap.org/
[29] https://www.datacentermap.com/
[30] http://blogs.hawk-hhg.de/memphis/ and http://cities.ait.ac.at/uilab/udb/home/memphis/
[31] https://cities.ait.ac.at/projects/hotcity/
[32] https://www.tasio-h2020.eu/wp-content/uploads/2018/02/D2.2-Heat-recovery-potentials-in-the-most-demanding-processes.pdf
[33] https://globalcompact.at/en/zehnprinzipien/brau-union-oesterreich/

develop and valorise the EU supply chain (EU leadership in energy efficiency equipment for domestic Neighbourhood & international).

2 – Technical

Challenge: Temporal mismatch

Possible solutions and good practice:

➔ District cooling and thermal driven chillers to increase summer heat demand

- For handling the summer surplus heat, adsorption or absorption chillers are a sensible option. Unlike compression chillers that use electricity, adsorption / absorption chillers use heat as an energy source for providing cooling services[34]. Herby it is important to note, that the higher the temperature level of the heat is, the higher is their efficiency. Standard adsorption systems require 65 -70°C, and 75 -80°C for absorption technology[35]. However, higher temperatures give higher efficiencies.
- Since there is usually a surplus of heat from various sources in summer times and there is a good match to the general cooling demand, absorption chillers are used in different district cooling networks worldwide. Prominent examples of absorption chiller driven district cooling networks are Berlin, Copenhagen, Helsinki, Stockholm, Paris and Vienna, see e.g. [36], [37]. However, currently the main heat source is either waste heat from CHP processes or waste incineration.
- On the other side, there is a trend of decreasing CHP production in summer times due to the increasing share of electricity production from solar PV. Additionally, the cooling demand is by trend increasing in summer times, with a growing popularity of district cooling. This is resulting in an opportunity for using waste heat sources in summer times.

Challenge: Temporal mismatch

Possible solutions and good practice:

➔ Multi-functional seasonal storages

- Using seasonal storages, the surplus heat in summer times can be stored for transition or winter times, substituting at the same time fossil heat supply units and thus are an interesting option. For

[34] *COOL CONCLUSIONS - HOW TO IMPLEMENT DISTRICT COOLING IN EUROPE*, a report from the RESCUE project, https://www.euroheat.org/wp-content/uploads/2016/04/RESCUE_Cool_Conclusions.pdf

[35] Calderoni M, Babu Sreekumar B, Dourlens-Quaranta S, Lennard Z, Rämä M, Klobut K, Wang Z, Duan X, Zhang Y, Nilsson J, and Hargo L. *Sustainable District Cooling Guidelines*. IEA DHC/CHP Report, 2019

[36] BASREC, *Best Practice Sharing, Municipal Energy Integration, Booklet 3 -District Cooling*, July 2015, http://basrec.net/wp-content/uploads/2015/01/Booklet-3-District-Cooling.pdf

[37] Galindo Fernández, M., Roger-Lacan, C., Gährs, U., Aumaitre, V., ***Efficient district heating and cooling systems in the EU -Case studies analysis, replicable key success factors and potential policy implications***, EUR28418 EN , doi: 10.2760/371045, https://publications.jrc.ec.europa.eu/repository/handle/JRC104437

this purpose, various technologies are available and tested in practice, including aquifer, borehole, pit and tank storages, e.g. [38] and [39].

- However, such systems have mainly been integrated in small/rural networks or building clusters in Germany, Denmark and Sweden focussing on solar thermal energy integration, e.g. [40], [41]. For larger, urban DH networks, seasonal storages have very little been implemented so far, examples of concrete planning activities include Graz[42], Hamburg[43] and Copenhagen. One of the main barriers for the integration of seasonal storages in urban DH networks is their limited temperature range. If the seasonal storage should be used for storing high shares of waste heat, large volumes are required, resulting in high investment costs (in the order of magnitude of 100 mil. Euros). The connected investment risk considering the usually long payback periods is another major barrier.

- In general, the number of charging cycles is crucial for the economic feasibility of storages. A study of waste heat integration in the DH system in Linz (Austria) shows, that the payback period for the seasonal storage can be reduced to about 20 years (ideal case) by operational optimization and multi-use fostering a higher degree of short term charging/discharging and as a consequence enhancing the operation of the existing CHP plants and reducing the use of the peak load boiler[44].

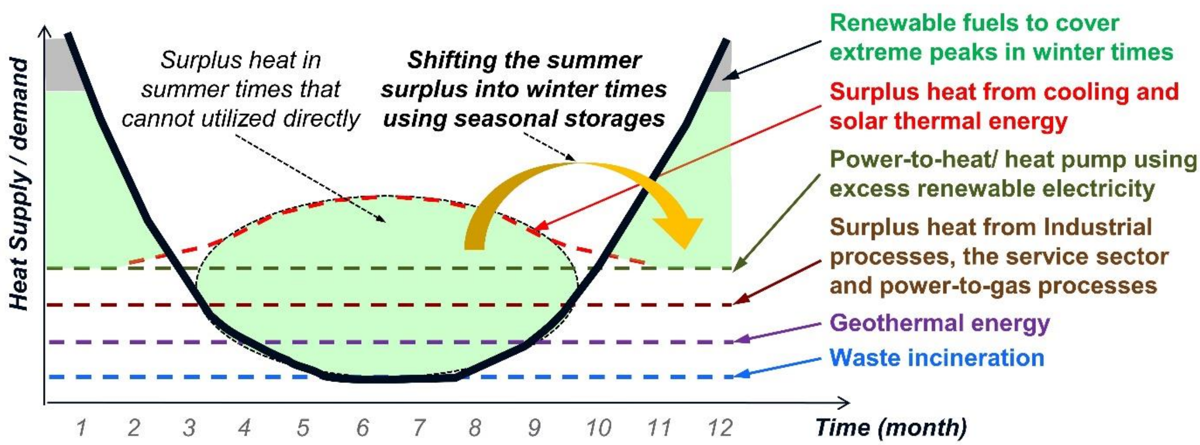

Figure 2: Shifting the summer surplus into winter times using seasonal storages (source: AIT)

Challenge: Temporal mismatch

Possible solutions and good practice:

38 J. Xu, R. Wang and Y. Li, "A review of available technologies for seasonal thermal energy storage" Solar Energy, vol. Volume 103, pp. Pages 610-638, 2014. https://doi.org/10.1016/j.solener.2013.06.006

39 P. Pinel, C. A. Cruickshank, I. Beausoleil-Morrison and A. Wills, "A review of available methods for seasonal storage of solar thermal energy in residential applications" Renewable and Sustainable Energy Reviews, vol. volume 15, p. pages 3341–3359, 2011.https://doi.org/10.1016/j.rser.2011.04.013

40 D. Bauer, R. Marx and H. Drück, "Solar District Heating Systems for Small Districts with Medium Scale Seasonal Thermal Energy Stores," Energy Procedia, vol. Volume 91, pp. Pages 537-545, 2016.https://doi.org/10.1016/j.egypro.2016.06.195

41 L. Gao, J. Zhao and Z. Tang, "A Review on Borehole Seasonal Solar Thermal Energy Storage" Energy Procedia, vol. Volume 70, pp. Pages 209-218, 2015.https://doi.org/10.1016/j.egypro.2015.02.117

42 https://www.solarthermalworld.org/news/land-secured-big-solar-graz and Patrick Reiter, et al.: BIG Solar Graz: Solar District Heating in Graz – 500,000 m2 for 20% Solar Fraction, Energy Procedia, Volume 91, 2016, Pages 578-584, https://doi.org/10.1016/j.egypro.2016.06.204

43 https://www.solar-district-heating.eu/hot-stuff-an-aquifer-heat-storage-for-hamburg/

44 M. Köfinger, R.R. Schmidt, et al., Simulation based evaluation of large scale waste heat utilization in urban district heating networks: Optimized integration and operation of a seasonal storage, Energy, https://doi.org/10.1016/j.energy.2018.06.192

➔ Heat to power system

- Waste heat recovery from energy intensive industrial processes to generate useful heat for DH as well as green power via ORC processes, mainly for self-consumption in the industrial process (boosting energy efficiency, sustainability, competitiveness, innovation, …).

Challenge: Locational mismatch

Possible solutions and good practice:

➔ Long heat transport networks

- Although heat generation and consumption are commonly perceived as a strictly local issue, there is the possibility to transport heat energy via pipelines over long distances, and thus enabling one to use waste heat from remote industries. There are some projects already realized featuring long heat transport networks with distance covered typically up to 30–50 km and more[45]. Currently, also 100 km long transport networks are currently discussed in China[46]. Here, in principle, two types of heat transport networks can be distinguished:

- <u>Single supplier and single consumer networks:</u> One prominent example is the heat transport line from the power plant Dürnrohr (CHP and waste incineration) to the city of St. Pölten (52.000 inhabitants) in Austria[47]. With a total length of 31 km and a diameter between 0.4 and 0.45 m, an average amount of 200 GWh per year is delivered, covering about 2/3 of the demand. Such transport pipes have high investment volumes and are usually possible with long term contracts and limited parties involved.

- <u>Multiple supplies and multiple consumer networks:</u> Those systems have a lower risk of stranded investments due to the involvement of several supply and demand nodes. One example is the connection between the Danish cities *Kolding, Fredericia, Middelfart and Vejle*[48]. The system has a total length of 80 km and has been in Operation since the 1980s. It is a cooperation between 8 DH companies with a total supply of about 1,400 GWh per year. The heat sources include waste incineration, waste heat from a refinery and a CHP plant. Another example is the DH transport network *Niederrhein*[49]*.* With a total length of 40 km and a

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[45] K.C. Kavvadias K.C, S. Quoilin, Exploiting waste heat potential by long distance heat transmission: Design considerations and techno-economic assessment, Appl Energy, 216 (2018), pp. 452-465, https://doi.org/10.1016/j.apenergy.2018.02.080

[46] Jianjun Xia: *District Energy Systems in China, Options for Optimization and Diversification*; 5th International Conference on Smart Energy Systems Copenhagen, 10-11 September 2019 https://smartenergysystems.eu/wp-content/uploads/2019/09/Plenary_1_JianjunXiaSESAAU2019.pdf

[47] Oberhammer, A.: *Die längste Fernwärmeleitung Österreichs, Bericht über die Planung, den Bau und die Qualitätssicherung*, Vortrag anlässlich der Fernwärmetage 2010, 17. –18. März 2010

[48] Bjørn, H; Kristensen, k.; Hammer, F.: *District heating based on surplus energy*, INTERNATIONAL MAGAZINE ON DISTRICT HEATING AND COOLING, N0. 2 2009, http://www.e-pages.dk/dbdh/8/6

[49] Auf dem Weg zu einer Energiewende - Roadmap für das Ruhrgebiet, 17.06.2015

diameter of up to DN 400, 15 substations to larger customers, various heat sources (waste heat, biomass, CHP, gas boiler) and storages are connected with a total heat supply of 878 GWh per year. It was built between 1980 and 1983 and is a cooperation of the Stadtwerke Duisburg AG and Stadtwerke Dinslaken GmbH. A feasibility study of the *Fernwärmeschiene Rheinland*[50] (Germany) shows the potential to collect 1.500 GWh waste heat per year on a total length of 41 km and a diameter of DN 500. Sweden largest heating network connects the three heating networks of *Lund, Helsingborg and Landskrona*[51], bringing the total network length to 90 km.

Challenge: Quality mismatch

Possible solutions and good practice:

➔ Low and ultra-low temperature networks

- Whereas many waste heat sources have lower temperatures as the system temperatures of existing DH networks, and its direct supply is only possible via heat pumps, for new networks it is possible to design them from scratch as a low temperature network adapted to the waste heat source temperature. This concept has been defined as the so-called "4th generation" of DHC networks[52]. The supply temperatures are usually between 50°C and 60°C (up to 70°C). There has been plenty of research done and several projects have been realized in the recent years on a European and international level.

- A further reduction of the network temperatures leads to the so-called "5th generation" of DHC networks, also called "Anergy networks"[53]. Here, "neutral" temperatures between 5°C and 25°C (up to 40°C) are used together with consumer-side heat pumps for boosting the network temperature to the demand side requirements. Those networks often use seasonal storages for the integration of surplus heat from cooling processes in summer times and local waste heat sources such as data centers. Some first Anergy networks have been installed in Germany and Switzerland, e.g. in Friesenberg[54] and ETH Campus Hönggerberg[55] (both Switzerland) using waste heat from data centres and the Wüstenrot system (Germany) using shallow geothermal energy and waste heat from a supermarket[56].

[50] Machbarkeitsstudie Fernwärmeschiene Rheinland, Kurzfassung Endbericht, EEB ENERKO Energiewirtschaftliche Beratung GmbH Aachen/Aldenhoven, Dezember 2019, https://enerko.de/wp-content/uploads/2020/01/191212-Kurzbericht-FW-Schiene-Rheinland.pdf
[51] https://www.dhcnews.net/sweden-unveils-largest-heating-network/
[52] Henrik Lund, Sven Werner, Robin Wiltshire, Svend Svendsen, Jan Eric Thorsen, Frede Hvelplund, Brian Vad Mathiesen, *4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems*, Energy, Volume 68, 2014, Pages 1-11, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2014.02.089
[53] Simone Buffa, Marco Cozzini, Matteo D'Antoni, Marco Baratieri, Roberto Fedrizzi, *5th generation district heating and cooling systems: A review of existing cases in Europe*, Renewable and Sustainable Energy Reviews, Volume 104, 2019, Pages 504-522, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2018.12.059
[54]https://heatpumpingtechnologies.org/annex47/wp-content/uploads/sites/54/2018/12/annex-47sub-projetcsanergy-network-friesenberg.pdf
[55] https://ethz.ch/content/dam/ethz/main/eth-zurich/nachhaltigkeit/Dokumente/Anergienetz/200129_Anergienetz_A4_6s_Einzel_EN_RZ.pdf
[56] Pietruschka D. Kalte Nahwärme: agrothermische Wärmeversorgung einer Plusenergiesiedlung. Geotherm 2013

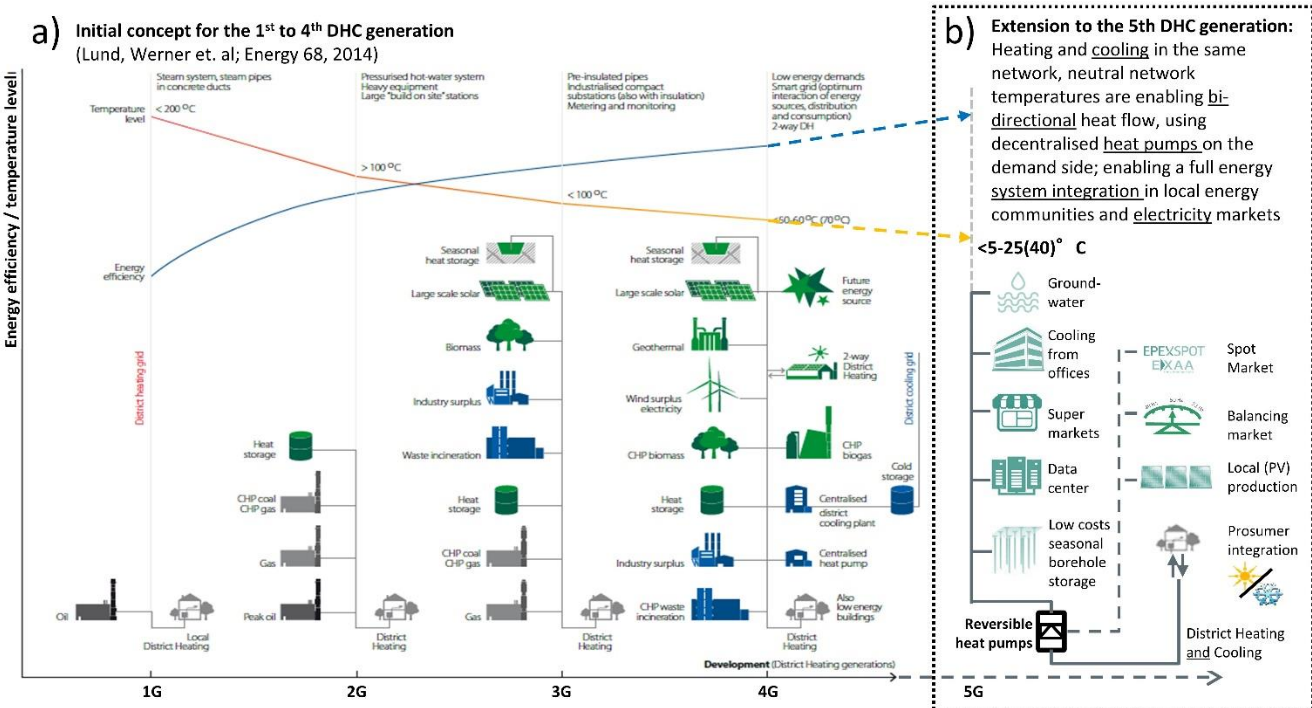

Figure 4: a) the concepts for the 1st to 4th generations of DHC networks from Lund et al[57], b) extension of this concept to the 5th generation (source: AIT)

Challenge: Quality mismatch

Possible solutions and good practice:

➔ Efforts for reducing the system temperatures in existing networks

- Existing DH networks usually have relatively high system temperatures (i.e. supply temperatures between 65°C and 120°C, up to 150°C and return temperatures between 50°C and 60°C, up to 80°C) that are a barrier for a direct supply of many waste heat sources. In turn, reducing the system temperatures would lead to direct benefits for integrating different low-grade waste heat sources.
- Further benefits of lower system temperatures include a higher potential for other alternative heat sources, such as solar thermal and geothermal energy as well as higher efficiencies in the heat distribution, power generation from steam-based CHP units including flue-gas condensation and increased capacities for connecting new customers and in water-based heat storages.
- However, the main technical barriers to lower network temperatures typically lie on the secondary side – the customer. The supply temperature must satisfy the requirements of the building heating systems and the cooling of the DH water is depending on the performance of the substation and the secondary side systems for heating and domestic hot water preparation.

[57] Henrik Lund, Sven Werner, et al: 4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems, Energy, Volume 68, 2014, https://doi.org/10.1016/j.energy.2014.02.089

- Several faults might occur either in the substation or in the secondary system (e.g. design of heat exchangers, setpoints, missing hydraulic balancing), leading to high return temperatures. There are a couple of national and international projects working on technical solutions (e.g. algorithms for identifying, operational optimization for reducing return temperatures[58]) and business models for correcting the faults (e.g. motivation tariffs), see also[59]. However, there has been no universal solution identified until now.

Challenge: Quality mismatch

Possible solutions and good practice:

➔ New and alternative heat pump technologies

- Additional to the "classical" compression heat pump, there are a couple of new and alternative heat pump technologies in development / on the market e.g. adsorption, super-critic cycles, stirling processes.
- Another interesting new development are rotational heat pumps, that can reach high temperatures up to 140°C, can deal with fluctuating sources and sinks, and achieve a high temperature rise of up to 120 °C; together with low operational costs[60]
- Innovative heat pump technologies for upgrading waste heat to process heat streams at temperature levels up to 160 °C, are also developed and demonstrated[61]
- A fair assessment should be made globally on the best Levelized cost of energy

Challenge: Quality mismatch

Possible solutions and good practice:

➔ Changing the processes towards higher temperatures (e.g. data centres)

- *"If the mountain will not come to Muhammad, Muhammad must go to the mountain"*
- Since significant temperature reductions in DH networks can only be achieved in a medium to long term (see above), one alternative option is to change the processes that are generating the waste heat towards higher temperatures.
- Here, examples can be found for high temperature cooling of data centres: New technology such as immersed servers (liquid cooling) starts to appear which could make cooling and thus heat recovery easier. One application is the supercomputer system "Aquasar" which uses hot water

[58] https://www.tempo-dhc.eu/
[59] Paolo Leoni, Roman Geyer, Ralf-Roman Schmidt, *Developing innovative business models for reducing return temperatures in district heating systems: Approach and first results*, Energy, Volume 195, 2020, 116963, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2020.116963
[60] https://www.ecop.at/en/home-4/
[61] http://dry-f.eu/

cooling. It was developed by IBM in 2010 and its waste heat at 60°C is used to warm the buildings at the university campus at ETH[62]. Similar options are investigated in the CATALYST Project[63].

3 – Economic and financial

Challenge: high investment risks

Possible solutions and good practice:

➔ Risk mitigation via insurance systems and credit facility

- The risk connected to the investments into waste heat projects are a major challenge. Within the geothermal sector, similar challenges appear, since geothermal drillings have high investment costs and uncertainty, as drillings could fail.

- Within the GEORISK project[64] an inventory of existing risk mitigation schemes (public, private and public-private) for geothermal projects has been investigated. A very prominent example is the French fund. It was created in 1980 and it is owned by different private and state banks and funds. Using some investment from the French government and fees paid by the public or private developers, a guaranteed fund is created that offers reimbursement in case of failure. End of 2017 the resources of the fund were at 13,8 M€ and 31 short / 15 long term contracts had been signed.

- The uncertainty and inherent risks linked to geothermal projects differ from those of waste heat projects, these schemes are not directly transferable to waste heat, but similar ideas could be explored, at national or European levels.

- ADEME, the French environment and energy agency, is developing an industrial waste heat risk grid analysis and associated mitigations. The agency will also train Finance actors to waste heat financing projects.

- Within the ReUseHeat project, the idea of a credit facility was developed, that covers some portion of the risk for waste heat recovery projects in order to bridge the gap between waste heat recovery projects and investors[65]. The facility would minimise the risk for the commercial bank due to technical assistance and (if required), involve public guarantee to cover possible defaults. The benefits for the project proponent are a free technical support, easier bankability and higher profitability[66].

Challenge: high investment risks

Possible solutions and good practice:

➔ Long term financing of sustainable projects

[62] https://en.wikipedia.org/wiki/Aquasar
[63] http://project-catalyst.eu/
[64] https://www.georisk-project.eu/
[65] Edward Wheatcroft, Henry Wynn, Kristina Lygnerud, Giorgio Bonvicini: *The role of low temperature waste heat recovery in achieving 2050 goals: a policy positioning paper;* ReUseHeat project, December 13, 2019; https://doi.org/10.3390/en13082107
[66] Giorgio Bonvicini: ReUseHeat proposal for a Credit Facility for Urban Waste Heat Recovery Projects - "How to ensure waste heat recovery investments?" Brussels, October 2nd, 2019; https://www.euroheat.org/wp-content/uploads/2019/09/Credit-Facility_Giorgio-Bonvicini.pdf

- There is in general a greater demand for sustainable investments and bonds from different investors. The recognition of waste heat investments is a first good step to increase the number of projects:
    - "EU Taxonomy", the report of the Technical Expert Group on Sustainable Finance (TEG)[67] lists waste heat as an economic activity that makes a substantial contribution to climate change mitigation, the report will feed into an EU legislation establishing a unified classification system for sustainable economic activities, an EU green bond standard, methodologies for low-carbon indices, and metrics for climate-related disclosure.
    - European Investment Bank lending criteria[68]: Waste heat is not directly mentioned but is eligible under the revised lending policy criteria. The bank supports the rehabilitation or extension of existing district heating networks, or construction of new networks to increase their sustainability, under the definition of efficient district heating[69]. Thermal storage facilities are also considered to be a network investment and can be supported.

Challenge: Long payback periods due to high investment costs

Possible solutions and good practice:

➔ Subsidies and other financial support for waste heat recovery

➔ There are several direct and indirect subsidies for waste heat extraction and its use in DH networks on national and regional level for reducing payback periods and making investments more attractive. Some examples include:

- The German Wärmenetz 4.0 scheme[70] provides funds for up to 60 percent of the cost of feasibility studies and 50 percent of eligible project costs for the realization of those studies. However, waste heat is considered on a level playing field with other renewable energy sources.
- Since 2011 with the EEN 9-11 the Italian Energy Management Authority (ARERA) has introduced the eligibility of Waste Heat Recovery in the White Certificate scheme, allowing a 5 year benefit. Since 2017 with the Decree DM 11 Gennaio 2017 a specific incentive scheme for waste heat recovery with Organic Rankine Cycle systems has been introduced, allowing a 10 year benefit[71].
- France has already put in place a series of measures to foster waste heat recovery:
    - Special fund (350 M€/y) to support investment in renewable heat (including DHC and heat & cold recovery). 62 projects of waste heat recovery in less than 10 years[72].

[67] TEG report and technical annex https://ec.europa.eu/info/sites/info/files/business_economy_euro/banking_and_finance/documents/200309-sustainable-finance-teg-final-report-taxonomy_en.pdf
[68] https://www.eib.org/attachments/strategies/eib_energy_lending_policy_en.pdf
[69] "Efficient district heating and cooling" means a district heating or cooling system using at least 50% renewable energy, 50% waste heat, 75% cogenerated heat or 50% of a combination of such energy and heat, in line with the EU Energy Efficiency Directive.
[70] https://www.bafa.de/DE/Energie/Energieeffizienz/Waermenetze/waermenetze_node.html
[71] Input during the stakeholder process from Marco Baresi, Turboden
[72]https://www.ademe.fr/expertises/energies-renouvelables-enr-production-reseaux-stockage/passer-a-laction/produire-chaleur/fonds-chaleur-bref

- Insulation of pipes and singular points of a heat network are eligible for white certificates[73].

Challenge: lack of standardised contracts

Possible solutions and good practice:

➔ The development of standardised contracts

- Standardized contracts should result in more efficient negotiations of contractual arrangements and transparency. One option would be to cluster situations where standards clauses in contract could be drawn, for instance waste heat recovery from supermarkets. From the perspective of the heat supplier, contracts should be kept as simple as possible. However, there is a trade-off to contracts tailored towards the needs of the DH company.

- Good design of heat supply contracts should include[74]

  - Shared Incentive: both parties are incentivised to continue with the arrangement; Split incentives (i.e., areas in which the two parties are incentivised by conflicting actions) should also be closely monitored.
  - Details of Supply: Specify: how much heat should be supplied, at what temperature and during which hours; details of the payments; quality control; responsibilities for monitoring the temperature of the heat; maintenance activities that affect supply; cost of the waste heat (e.g. a tariff per unit of heat; outside temperature dependent tariffs; time dependent tariffs (free in the summer and for a fixed fee per unit in the winter).
  - Resources: specify what resources are needed for heat recovery, who is responsible for their supply (e.g. supply of electricity for the heat pump, or supply of water as a heat carrier medium)
  - Communication Channels: specify details of communication channels and the frequency of communication
  - Operational Activities: involvement in DH is not the core business of the heat supplier. The supplier is unlikely to be willing to spend significant time understanding the complexities à keep such arrangements simple.
  - Renegotiation: allow for flexibility in the long-term nature of heat supply contract, thus reducing the risk. The outcome of negotiations will of course depend on the respective bargaining positions of each party.
  - Mitigation: Actions to be taken, and by which party, when difficulties arise should be written carefully and unambiguously into the contract

Challenge: long term guarantees, value of the heat and amortisation time

Possible solutions and good practice:

➔ Successful business models from the Danish perspective:

[73] https://centre.ademe.fr/entreprises-et-monde-agricole/les-certificats-deconomie-denergie-cee

[74] Kristina Lygnerud, Edward Wheatcroft and Henry Wynn: *Contracts, Business Models and Barriers to Investing in Low Temperature District Heating Projects*; Appl. Sci. 2019, 9, 3142; doi:10.3390/app9153142

A collaboration between the DH operator and the company that "owns" the waste heat can be organized in several ways. A Danish publication[75] gives an overview of the 3 most common models:

- The DH operator has the investment and ownership: This is usually done in cases where the business operations is not affected by the extraction of the waste heat, e.g. for flue gases. The heat utilization requires significant investments with consequently long payback time, which companies usually are not interested in. However, DH companies are interested to invest only if the company has a sound and stable future operation. Such investments risks must be covered in the contract. The payment for the excess heat is usually low to modest.

- The company has the investment and ownership: This is usually done in cases where the company's operations have a close correlation with the utilization waste heat and the waste heat can be extracted without significant investment and / or operation costs. The repayment period of the company's investment will typically be short. The company has to commit to allocate the waste heat from the process to the DH network at an agreed flow temperature. Payment to the company for the excess heat will therefore be higher than the first model.

- Mixed investment and ownership. This is usually done in cases where the company has a high interest in having control over the processes for waste heat extraction. This applies e.g. for refrigeration systems, where the cooling side is fully integrated into the process and the coupling of the heating side to the DH network is costly and thus invested by the DH operator. This is often an ideal partnership, especially when sharing the economic benefits and both parties having the same interest in optimizing the system. However, such joint projects require transparency about their processes and economic benefits – and this is sometimes a difficult step for companies. Also, contractual arrangements are more complex.

- A third party invests in the plant: This is a theoretical model that has never been applied in practice. Here, external investors invest in the installation for waste heat extraction as a "sustainable energy project". Subsequently, they purchase the heat from the company and sell it to a DH operator.

4 – Legislative

Challenge: Nascent framework and lower visibility of waste heat as a sustainable heat source

Possible solutions and good practice:

Reinforcing the EU framework to better encourage waste heat recovery

➔ A uniform CO2 price across the heating sector

- The most efficient type of policy measure to drive the decarbonisation of heating and cooling, increasing the share of renewables and waste heat, would be to ensure a level-playing field in the heating sector for instance with a carbon tax or an extension of the scope of the EU ETS to buildings.

[75] INSPIRATIONSKATALOG 10 eksempler på samarbejde mellem fjernvarme og industri; https://www.danskfjernvarme.dk/-/media/danskfjernvarme/gronenergi/projekter/inspirationskatalog---februar-2020.pdf

➔ Equal treatment of waste heat sources and renewables

While it is still difficult to anticipate the transposition and implementation of the new Renewable Energy Directive:

- Treating all waste heat sources equally and on par with renewables without a differentiated target would be beneficial for a **more stable and consistent framework to promote waste heat across EU legislation**, also enabling waste heat to be accounted towards the national renewable energy target.

- A broad definition serves energy and climate objectives well, this definition should stay uniform across the different EU legislation.

➔ Promote the visibility and the use of the results of the EED Comprehensive Assessments

- Member States must prepare their new National Comprehensive Assessments by the end of 2020 (see Part II, 1 - General). The Commission when communicating with Member States on this exercise should emphasize the need to provide a good assessment of waste heat potential.

- Member States should ensure the participation of stakeholders in the preparation of the Comprehensive Assessment, including the energy sector, cities, local and regional authorities that will play a role in the planning and refurbishment of heat infrastructure.

- Identifying waste heat potential is a key step towards better managing and utilising waste heat. It strengthens energy planning and support mechanisms and helps trigger investments in waste heat recovery. The Comprehensive Assessments should be a tool to support planning at city, local and regional levels and also be translated in national plans, for instance the National Energy and Climates Plans. They should be more visible, promoted and disseminated towards actors involved in energy planning. They should also be the basis for concrete measures, as implied in article 14 4. of the EED[76].

➔ EU to promote best practices and incentivise Member States to adopt measures to promote waste heat recovery

- Countries have supported directly or indirectly the recovery and use of waste heat in different ways. The European Commission should better promote these best practices on waste heat in the framework of concerted actions[77] aiming at supporting the implementation of EU legislation.

- In Denmark, there are several measures in place that support DH including **heat planning regulation, taxation, subsidies, heat price regulation, CHP requirements, a ban on electrical heating and a law on district cooling**[78]. However, the current electricity act stipulates that CHPs are built with the main ambition of generating electricity with mandatory heat recovery, this being a

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[76] Art. 14 4. Where the assessment referred to in paragraph 1 and the analysis referred to in paragraph 3 identify a potential for the application of high-efficiency cogeneration and/or efficient district heating and cooling whose benefits exceed the costs, Member States shall take adequate measures for efficient district heating and cooling infrastructure to be developed and/or to accommodate the development of high-efficiency cogeneration and the use of heating and cooling from waste heat and renewable energy sources in accordance with paragraphs 1, 5, and 7.
[77] In particular, the Concerted Action for the Energy Performance of Buildings Directive (CA EPBD), the Concerted Action for the Renewable Energy Sources Directive (CA RES) and the Concerted Action for the Energy Efficiency Directive (CA EED).
[78] Edward Wheatcroft, Henry Wynn, Kristina Lygnerud, Giorgio Bonvicini: *The role of low temperature waste heat recovery in achieving 2050 goals: a policy positioning paper;* ReUseHeat project, December 13, 2019

competitor for waste heat recovery. On the other hand, taxes on natural gas, a ban on electric heating in buildings and the growing interest of low temperature DH support the use of waste heat.

- Sweden has the largest percentage of waste heat from industries in its DH systems in the world[79]. There has been an early **support for carbon free technologies** and biomass-based CHPs[80]. In 1996, the Swedish heat market was deregulated, followed by institutional challenges such as a new DH law (2008), the threat of price regulation (2009) and third-party access (2009). The current Swedish policy currently neither promotes nor advises against using waste heat recovery in DH, however Sweden has introduced a CO2 tax as early as 1991. A new legislation placing a tax on waste incineration was announced in 2019, in combination with a new energy and C02 tax on CHP, it will be a challenge to Swedish CHPs. Also, the county administrative boards have sometimes been involved in/ordered potential studies but also managed meetings and invited stakeholders to discuss waste heat potential. They have acted as a facilitator in some cases and shared good practices examples.

➔ Italy: Since 2011 with the EEN 9-11 the Italian Energy Management Authority (ARERA) has introduced the **eligibility of Waste Heat Recovery in the white certificate scheme**, allowing a 5-year benefit. Since 2017 with the Decree DM 11 Gennaio 2017 a specific incentive scheme for waste heat recovery with Organic Rankine Cycle systems has been introduced, allowing a 10-year benefit[81].

➔ When receiving public funds to build new heat generation capacity or when a substantial refurbishment of a DH network takes place, a cost-benefit analysis could be requested with the demand for public financial support, to **assess the possibility of using waste heat in priority**, before new production capacity. In France, this is required for installations to benefit from the support of the Heat Fund[82].

➔ The French general tax code determines that the reduced VAT rate applies to the supply of heat when it is produced at least 50% from biomass, geothermal energy, waste and recovery energy (art. 278-0 bis of the French General Tax Code[83]).

➔ Empower cities, local and regional authorities, ensure the cooperation between governance levels

- The Renewable Energy Directive article 15 foresees competent authorities should consider waste heat utilisation when planning, including early spatial planning, designing, building and renovating urban infrastructure, industrial, commercial or residential areas and energy infrastructure. This provision should be further strengthened.

- Initiatives and projects that create or list heat mapping and planning tools should be further supported and disseminated to support local master planning.

[79] K. Lygnerud and S. Werner. *Risk of industrial heat recovery in district heating systems*. Energy Procedia, 116:152{157, 2017
[80] Edward Wheatcroft, Henry Wynn, Kristina Lygnerud, Giorgio Bonvicini: *The role of low temperature waste heat recovery in achieving 2050 goals: a policy positioning paper;* ReUseHeat project, December 13, 2019
[81] Input during the stakeholder process from Marco Baresi, Turboden
[82] Heat Fund eligibility criteria: https://www.ademe.fr/sites/default/files/assets/documents/fiche-descriptive-eligibilite-financement-reseaux-chaleur-2020.pdf
[83] https://ec.europa.eu/taxation_customs/tedb/taxDetails.html?id=299/1514764800

Challenge: Waste heat can have a high PEF value which make it less attractive as a heat source

Possible solutions and good practice:

➔ Allocation of renewable electricity for the temperature upgrade of waste heat

- When low temperature waste heat is upgraded through a heat pump, allocate renewable electricity to have a lower PEF value, matching the energy performance requirements and making the connection to district heating more attractive for buildings.

➔ Consider that waste heat is based on the energy efficiency principle and is emission-free

- Waste heat cannot be allocated fuels or emissions, as the emissions from the underlying economic activity would be generated with or without the waste heat recovery system. Integrating potential waste heat sectors (industry, renewable energy conversion, data centres etc.) with the heating and cooling sector increases the overall efficiency of the energy system and should be promoted.

5 – Societal & cognitive

Challenge: difficult to sell waste heat as a sustainable product to end-users and customers

Possible solutions and good practice:

➔ Closer customer dialogue

- A closer customer dialogue can build trust and long-term engagement, which can create a competitive advantage for DH providers. One example is Denmark, where individual district heating suppliers put a great effort involving their customers.

- Many Danish DH systems are operated as cooperatives, where the cooperative is owned by its own customers. The advantage is that the cooperative works to promote their common interests[84].

➔ Empower the different waste heat actors: foster better communication and spread knowledge[85]

- The benefits from waste heat recovery should be better communicated to potential waste heat owners: improve energy efficiency, save CO2, boost competitiveness (energy efficiency), foster investments in industrial sector (industrial strategy), boost sustainability (circular economy, SDGs), develop and valorise the EU supply chain (EU leadership in energy efficiency equipment for domestic Neighbourhood & international).

- Local forums for match-making and facilitating contacts and exchange between waste heat owners and district heating operators would help kick-start discussions on possible projects, in particular in industrial or port areas. This type of "soft action" appears in the recommendations stemming from the French inter-ministerial group on Heating and Cooling[86].

[84] https://www.danskfjernvarme.dk/sitetools/english/the-danish-model
[85] Also connected to general challenge "low interest and know-how of waste heat owner"
[86] https://www.ecologique-solidaire.gouv.fr/sites/default/files/2019.10.07_eb_ew_dp_reseauxchaleurfroid.pdf

- Spreading know-how and good practices is also very important for companies and DH-networks that have no experience on use of waste heat.

- Training and awareness raising of people involved in negotiations for waste heat recovery contracts would also help.

- Empower cities to find the right tools and expertise. Planning is key for waste heat recovery, whether it is the start of a new district heating network from scratch or switching from fossil fuel to waste heat. Not all cities can be forerunners, and even the ones that are need access to expertise and the right tools.
    - EU projects such as the Celsius initiative can support cities in their decarbonisation efforts by providing networking opportunities, expert support, peer review and tools.

6 – Best Practices: concrete project examples

This section aims at further illustrating waste heat recovery with concrete or in development projects across Europe, in addition to the examples mentioned in specific sections of part II. It is divided between industrial and tertiary waste heat recovery and tries to give some key facts and characteristics as well as a link to access more information on these projects.

Industrial waste heat

Material processing

- Aurubis copper plant in Hamburg, HafenCity, Germany[87]
    - Hamburg to reduce its CO2 emissions by 80% (1990) in 2050
    - DH operator Enercity supplies 87% of a District with heat recovered from Aurubis plant
    - Supplies 8000 households but potential for 25,000
- FP7 Project Pitagoras, Steel company ORI Martin in Brescia, Northern Italy[88]
    - This joint project promotes the cooperation among a steel industry (ORI Martin), a multiutility (A2A), a research centre (CSMT) and a technology provider (Turboden) with a strong commitment of local population and municipality of Brescia
    - Recovers up to 10 MWth of wasted heat from a steel industry to feed a District Heating (heat to heat) and produces 3 MWe power (heat to power) - steel company ORI Martin in the North of Italy, Brescia

Food & drinks

- Waste heat recovery in the coffee roastery Paulig, Vuosaari, Helsinki region, Finland[89]
    - Waste heat generated by the food industry production processes to the district heating network is unique in the Helsinki region
    - Covers the annual heat demand of 1,000 two-room apartments
    - The two-way district heating markets or open district heating means that the company can both buy district heat as well as sell waste heat.

[87] https://copperalliance.eu/uploads/2018/02/case-study-aurubis-hafencity.pdf
[88] https://www.youtube.com/watch?v=ApBnI4_WSxo
[89] https://www.pauliggroup.com/news/waste-heat-recovery-in-a-coffee-roastery

Waste heat from the tertiary sector

Multi-sources & buildings

- Hoje-Taastrup (Østerby) – Copenhagen region, Denmark – COOL DH project[90]
    - At the moment in Høje-Taastrup the DH is based on 49% fossil and the CO_2 emission factor is 98 kg/MWh (2015). The project will use low-grade surplus heat, increasing efficiency and further reducing these emissions.
    - Project started in October 2017 to be delivered in September 2021. It is expanding and refurbishing existing DH networks
    - The waste heat will be harvested from the cooling of the CITY2 Mall, whose rooftop is covered in PV panels, the electricity will be used to operate heat pumps that upgrade the heat. Cooling of the servers at the Danske Bank data centre and hotels.
- Helen, underground heating and cooling plant located under the Esplanade Park, Helsinki, Finland[91]
    - Operation started in 2018. Two new heat pumps: 2 x 11 MW of heat and 2 x 7.5 MW of cooling. The heat pumps will increase the total cooling output of the Esplanade cooling centre to 50 MW (new heat pumps 15 MW and the existing cooling accumulator 35 MW).

Data Centre

- Funnen District Heating, Odense, Denmark[92]
    - Largest DH grid in the World
    - Coal phase out by 2025
    - Combination a large heat pump plant (TBV) with CHP biomass unit and storage facility
    - HP connected to Facebook Data Centre - cooling is provided to the data centre
    - 100.000 MWh surplus heat ~ 6900 households

Metro Station

- Islington Borough, Bunhill Energy Centre 2 and GreenSCIES, London, United Kingdom[93]
    - Islington's committed to be a net zero carbon borough by 2030
    - Heat is extracted from the tunnels of the London Underground Northern Line from the former City Road station, with underground fan
    - Bunhill 2 Energy Centre adds 550 homes and a primary school to the existing Bunhill Heat and Power DH network, launched in 2012
    - The site has potential to connect more buildings.
    - The DH network reduces CO2 emissions by around 500 tonnes each year and the new project has allowed to reduce the heating bills of the tenants connected to the network by 10 per cent compared to other communal heating systems.

Other

Waste heat from power-to-gas processes

- Research-Project "Stromlückenfüller", realizing a Power-to-Gas-to-Power concept[94]
    - Development of a megawatt PEM (proton electrolyte membrane) stack.

[90] http://www.cooldh.eu/demo-sites-and-innovations-in-cool-dh/osterby-hoje-taastrup/ AND https://www.euroheat.org/knowledge-hub/case-studies/hoje-taastrup-osterby-copenhagen-region-denmark-cool-dh-project/
[91] https://www.helen.fi/en/news/2018/underground-heating-and-cooling-plant-utilises-waste-heat
[92] https://www.euroheat.org/knowledge-hub/case-studies/100-re-district-odense-denmark/ AND https://sustainability.fb.com/wp-content/uploads/2019/06/Waste_Heat_Recovery_Final_Jun2019.pdf
[93] https://www.islington.media/news/bunhill-2-launch-pr AND https://uk.ramboll.com/projects/ruk/heating-up-london
[94] https://forschung-energiespeicher.info/projektschau/gesamtliste/projekt-einzelansicht//Stromlueckenfueller_der_Megawattklasse/

- Hydrogen is considered an important energy carrier.
- The waste heat from the stack can be used in local heating networks.
- A study from the German DENA[95] asked for more research for using waste heat as a by-product of the Electrolysis for feeding into the district heating network

Additional resources with concrete waste heat recovery cases as well as related strategies and measures

Celsius Initiative[96]: Celsius is a demand driven collaboration hub for efficient, integrated heating and cooling solutions supporting cities in their energy transition to carbon-neutral systems. It gathers and shares technical, economic, social and policy expertise. It connects members, exchanges and fosters innovation, leading to solutions that accelerate sustainable development in Europe and across the world. The initiative has created a toolbox for cities, with a repository of technical solutions for low carbon DHC networks, including waste heat recovery.

ReUseHeat Project[97]: ReUseHeat tackles both technical and non-technical barriers to unlocking urban waste heat recovery projects and investments across Europe. There are four large-scale demonstrators in the project, showing the technical feasibility and economic viability of excess heat recovery and reuse from data centres (Brunswick), sewage collectors (Nice), cooling system of a hospital (Madrid) and underground station (Berlin). The experience from running the demonstrators and from other examples across the EU will be consolidated into a handbook that will provide guidance for investors and project developers and support future uptake of using urban excess heat. The projects deliverable features a list of best practices cases.

Renewable Heating & Cooling Platform[98]:
The European Technology and Innovation Platform on Renewable Heating & Cooling (RHC-ETIP) brings together stakeholders from the biomass, geothermal, solar thermal and heat pump sectors – including the related industries such as district heating and cooling, thermal energy storage, and hybrid systems – to define a common strategy for increasing the use of renewable energy technologies for heating and cooling. The 100% Renewable Energy Districts: 2050 Vision" presents cases involving waste heat recovery.

CoolDH Project[99]: The objective of COOL DH action is to support cities in their endeavour to plan and deploy new, efficient district heating and cooling (DHC) systems, and extend and refurbish existing ones to higher standards. Thus, it will allow greater uptake of renewables, recovering of excess heat or cold while improving the overall efficiency of the systems.

DHC+ Technology Platform[100]: Set up under the umbrella of Euroheat & Power, DHC+ Technology Platform is the European hub for research & innovation in district heating and cooling.
It is today a strong group of stakeholders from academia, research, business and industry committed to move to a sustainable energy system. DHC+ has created a Knowledge Base with numerous case studies of DHC solutions.

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[95] https://www.dena.de/fileadmin/dena/Dokumente/Pdf/9096_Fachbroschuere_Systemloesung_Power_to_Gas.pdf
[96] https://celsiuscity.eu/toolbox/technical-solutions/
[97] https://www.reuseheat.eu/project-documents-newsletter/
[98] https://www.rhc-platform.org/
https://www.euroheat.org/wp-content/uploads/2019/08/RHC-ETIP_District-and-DHC-Vision-2050.pdf
[99] https://www.cooldh.eu/
[100] https://www.euroheat.org/knowledge-hub/case-studies/